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vol. 55
1944

PROCEEDINGS

OF THE

GEOLOGISTS' ASSOCIATION

(FOUNDED 1858).

VOLUME THE FIFTY-FIFTH
1944.

Edited by
G. S. SWEETING.

(Authors alone are responsible for the opinions and facts stated in their respective papers, and for the accuracy of their references.)

LONDON:
EDWARD STANFORD LTD.
12, 13 & 14, Long Acre, W.C. 2.
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VOLUME LV (1944).

Part 1.	pp. 1-44	24th March, 1944
,, 2,	pp. 45-119	28th July, 1944
,, 3,	pp. 121-193	27th October, 1944
,, 4,	pp. 195-229	26th January, 1945

PROCEEDINGS
OF THE
GEOLOGISTS' ASSOCIATION.

WEALDEN IRON ORE AND THE HISTORY OF ITS INDUSTRY.

(Weald Research Communication, No. 32.)

By G. S. SWEETING, D.I.C., F.G.S.

[*Received 24th August*, 1943.]
[*Read 2nd October*, 1943.]

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IN 1925 and 1930, the writer contributed two small papers to the *Proceedings* on the geology of various areas in East Sussex from which much iron ore had been extracted in earlier times. In the 1930 paper, some notes were added on " The Wealden Iron Ore," and attention is, therefore, directed to this communication, particularly for chemical analyses of the ore [**1***].

I. HISTORICAL.

To picture South East England with its present quiet and beautiful surroundings as an area of noise and smoke-laden skies would be a difficult matter. Such, however, were the conditions which prevailed in Sussex, Kent and Surrey during Tudor days. Sussex and Kent had from very early times been important producers of iron, and they were destined to become for a time the seat of the largest iron trade in the British Isles.

Iron being the most plentiful and accessible of the metals, it follows that it would be naturally one of the first to be employed by an early race. Though we have no certain knowledge of the beginning of the iron ore industry in South East England, we know that in early times the iron ore in the Weald was of such importance as to be noticed by Caesar before the Christian era, and by Strabo in 20 A.D. The Romans extracted iron on a large scale as is seen by the size of their workings ; in fact, during their occupation, there was much activity all over the Weald and iron became one of its chief exports. This is proved by the abundant heaps of iron slag found at Maresfield, Westfield, Seddlescombe, Crowhurst and Ashburnham in Sussex, and at Cowden and Tenterden in Kent. With these slag heaps, fragments of pottery and coins have been discovered belonging to the period of Vespasian (who was Emperor in 69 A.D.) and of Nero. Thus the industry must have thrived at least in the

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* For List of References see p. 14.

First Century. There is little trace or evidence of the industry having been carried on during the days of the Saxon settlement, that is for a period of about seven centuries after the departure of the Romans.

During the Middle Ages (10th-14th Centuries), however, the industry again began to develop. For example, during the reign of Edward III, important works were opened up at Tudeley near Tonbridge. In the years 1330, 1331 and 1332 these works turned out 194, 224 and 231 blooms of iron respectively, the output continuing to rise until 1335 when 600 blooms were produced. In Tudor time, late 15th and early 16th Centuries, the industry reached its culminating point.

Let us return for a moment, however, to the Middle Ages. Up to about the end of the 12th Century, the iron supply of London came almost entirely from the Forest of Dean. With the advantage, however, of being within much easier reach of the main market, the Weald from this time began to take the place of the Dean. For example, in 1253 the Sheriff of Sussex was ordered to send 12,000 nails to Freemantle (Hampshire) for roofing the Hall, and in 1254, 30,000 horse-shoes and 60,000 nails for the army [**2**]. It would appear that early production also included domestic utensils together with firebacks and iron grave-slabs. In Burwash Church there is a fine 14th Century monumental slab in cast iron. This is regarded by several eminent authorities as the first example of such work.

The main development of the Wealden iron industry took place in the reign of Henry VIII (1509-1547). So rapid was its growth that it quickly covered practically the whole of Sussex and West Kent. Camden in 1637, writing on Sussex, says " Full of iron mines it is in sundry places, where for the making and fining thereof, there be furnaces on every side, and a huge deal of wood is yearly spent, to which purpose divers brooks in many places are brought to run in one channel, and sundry meadows turned into pools and waters, that they might be of power sufficient to drive hammer mills, which beating upon the iron, resound all over the places adjoining " [**3**].

From this time, the industry ceased to be of a local character and assumed that of a national industry. Moreover, Wealden iron, of which the most important products were ordnance and shot, became closely connected with our foreign trade, especially to the Baltic. Thus output flowed and fluctuated depending on conditions of war or peace ; in fact, the industry thrived on war. The owner of Ashurst Furnace (Thomas Browne) was granted the monopoly of making iron and brass guns for the Navy, and Sackville Crowe of Maresfield Furnace the monopoly for merchant ships.

One of the chief works in Sussex in the late 16th Century was situated at Buxted (near Uckfield) on the southern margin of Ashdown Forest. Here, the improved process of gun founding was introduced, whereby cannon were cast as one whole piece and bored, instead of being wrought of separate parts banded together. The first cannon was cast at Buxted works in 1574 by Ralph Hogge, who was known as " The Queen's gun founder and gun-stone maker." In the course of his career as an ironfounder, Hogge was responsible for the production of a large number of guns together with a large quantity of munitions, most of which were sent to the Ordnance Office at the Tower. Hog House where this worthy lived still remains and bears a plaque on which is a black figure of a hog with the date 1583.

A larger iron industry was always carried on in Sussex than in Kent, while in Surrey iron manufacture did not commence until about 1550, and then only four furnaces were operating, viz., in Chiddingfold, Ewood, Copthorn and Lingfield. A list of works prepared by M. A. Lower [**9**, 1850] gives 38 forges and 32 furnaces in Sussex in 1574. After 1574 and up to 1653, other works

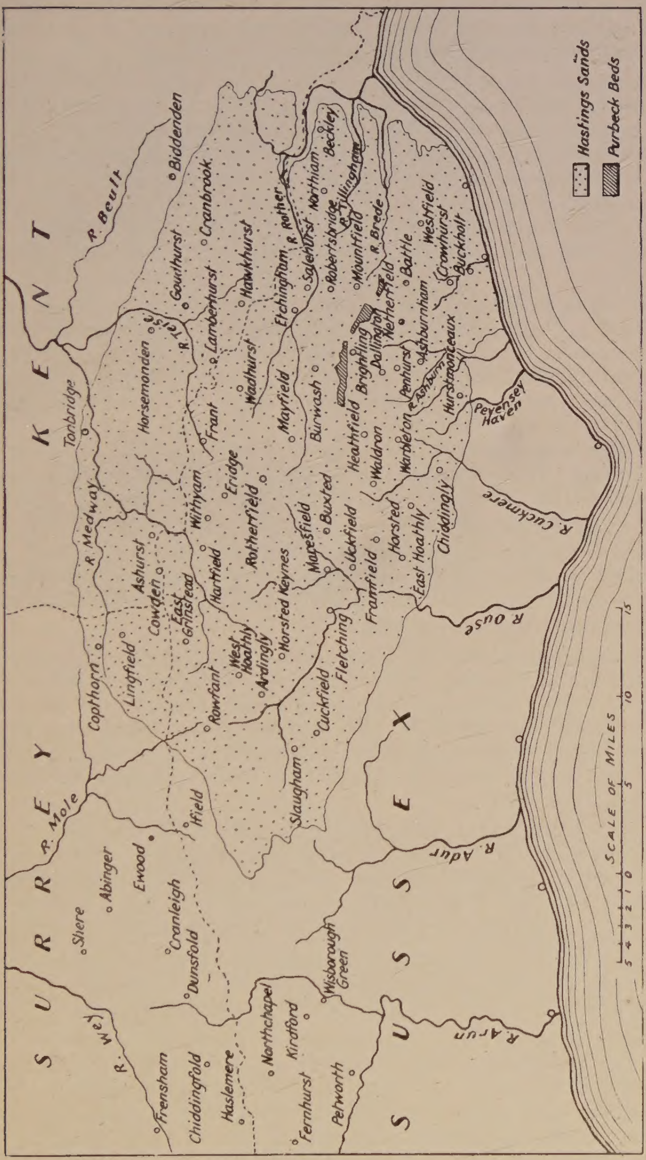

FIG. 1.—SKETCH MAP SHOWING DISTRIBUTION OF FURNACES AND FORGES IN THE WEALD, 1574-1653.

were opened-up in the Weald, but the centre of the industry remained in Sussex (see Map, Fig. 1). Sussex, indeed, now became the most important county in England, and its iron was recognised to equal the best the world produced. Moreover, it was this period which witnessed the first signs of a change from an almost entirely agricultural community to one depending for its livelihood on the export of manufactured goods.

In Elizabethan times the industry reached its peak and increasing demands were made for iron ordnance. Although no reliable figures are available of people employed in the industry, there is evidence that at that time a very large proportion of the existing industrial population of the Weald was so engaged. In 1653, 27 furnaces and 42 forges or iron mills were working in Sussex, viz., at Ashburnham, Penhurst, Brede, Robertsbridge, Crowhurst and Brightling [**9**, 1866]. The output of wrought iron from the Ashburnham and Penhurst forges was more than twice the amount produced from all other works in Sussex.

One of the most important towns throughout the history of the industry was Lamberhurst (on the borders of Kent and Sussex), which reached its most prosperous period about 1710, cannon being the chief article of production. It is interesting to recall, however, that the railings which once surrounded St. Paul's[1] were products of the Lamberhurst furnaces These railings, which were cast in the early part of the 18th Century, were of great weight and very costly. There were 2500 railings and seven ornamental gates, weighing altogether 200 tons. The iron cost 6d. per pound and the total expenditure reached £11,202 0s. 6d. [**4**].

The iron trade now offered a comparatively easy and profitable opportunity for acquiring wealth from timber and iron ore. Enterprising landowners soon became prosperous and London merchants came forward to finance the industry, trading in furnaces as investments or speculations, while skilled craftsmen became important and wealthy.

Notwithstanding the expansion and interest in the industry it is difficult to obtain information regarding actual tonnage of iron raised at this time. Few figures seem to be available, and where these are procurable they come from isolated and individual furnaces ; for example, in the 16th Century (1541-1573), two furnaces at Robertsbridge averaged 113 tons of iron annually, and, at a little later date, an average of 290 tons per year was reached over a period of six years.

During the 14th Century, iron was £9 a ton, but in 1539 the price dropped to £5-£7 per ton, with an extra 9s. per ton when carried to London or elsewhere ; shot was sold at £11 per ton in 1654 and cast iron at £15 per ton in 1658 [**5**].

The decline of the iron industry of the Weald was both rapid and complete and although much concern and trouble had arisen with respect to the destruction of woods and forests, the collapse was not due to this, but almost entirely to the introduction of pit-coal in place of charcoal for the furnaces.

The credit for having first solved the important technical problem of replacing charcoal by pit coal in smelting iron ore has been given to Dud Dudley (son of Edward Lord Dudley). In 1665, an account of his work was published, though the method he employed was not disclosed. It was not until well into the next century (1730) that Abraham Darby attempted, without success, to smelt with a mixture of raw coal and charcoal. About 1735, however, he treated pit-coal as the charcoal burners treated wood, and after many difficulties and disappointments his experiments succeeded " and the iron ran out well " [**6**].

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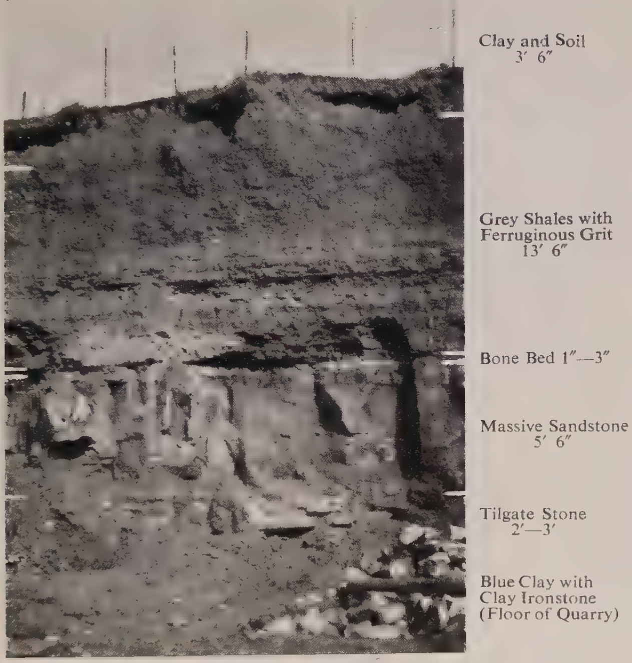
[1] The railings were partly removed in January, 1874 [7, p. 331].



A.—RACKWELL WOOD QUARRY, CROWHURST (SUSSEX), IN 1925.

[Photos A. J. Bull.

B.—ASHBURNHAM FORGE, SUSSEX.

[To face. p. 4.

Because of its cheapness and suitability, compared with charcoal smelting, this method quickly dealt a heavy blow to the Wealden industry. Unlike areas in the north of England, the Weald was never in a position to substitute coal for charcoal as a fuel, and this fact was destined in later years to bring about a complete end to the industry and to result in the Weald's reversion to its former agricultural life.

The beginning of the 18th Century, therefore, saw the gradual but decided shrinking of iron production and the dying down of furnace fires. In 1769, Sussex lost the Naval contracts, and although large numbers of men were still employed at Lamberhurst and Ashburnham, the "ironstone days" of the Weald were over. The last furnace, that at Ashburnham, closed down in 1828 (Pl. 1, B).

Therefore, after a period of possibly more than 2000 years since its appearance, we can trace a swift rise of the industry to its maximum importance followed by a decline ending in complete extinction a little over 300 years after the rise began. This extinction, in the author's opinion, was not due to exhaustion of woods nor for want of raw material, but from economic causes. In August 1857, an effort was made to revive mining—the ore being sent to Staffordshire for smelting – but this was abandoned a year later, in September, 1858.

II. THE IRON ORE.

(a.) Source and Composition.

Although a small amount of ore was obtained from the Folkestone Sands and Weald Clay, the main source of the iron was the Wadhurst Clay and Ashdown Sand. As, however, the Wadhurst Clay was probably by far the most important producer, this formation only will be considered.

The thickness of the Wadhurst Clay varies very much over the Weald. An average thickness can be taken at about 150 ft., a maximum of approximately 230 ft. occurring at Cuckfield. An almost full succession of rocks of this formation could until recently be studied at Rackwell Wood Quarry, Crowhurst (Sussex) [1, 1925, p. 410]. The section, unfortunately, is now no longer to be seen. Work at the quarry ceased early in the War (1939) and the face of the quarry is now (July, 1943) almost completely hidden by fallen material from above. Plate 1, A, shows a portion of Rackwell Wood Quarry as it appeared in 1925. The face of the quarry at this point is approximately 30 ft. high, the floor being about 15 ft. above the underlying Ashdown Sand. A good section of the 'Ashdown' occurs in the banks of a stream and close to the footbridge, about 150 yards due south of the quarry.

It is at the base of the Wadhurst Clay that much of the ore occurs. The basal bed consists of a dark blue or mottled clay which varies in thickness from 10 to 20 ft., and the ore is scattered through it as nodular or tabular masses. The nodules (called "Kernal Stones" by the quarrymen) vary in size from that of an orange to the size of one's head. (*Banded* clay ironstones—Blackband Ironstones—which are so common in Yorkshire, for example, are never found in the Weald).

A coating, or series of thin skins, usually surrounds the nodules. These skins consist entirely of limonite and, when peeled off, the pale grey to brown ironstone (siderite) is exposed ; newly fractured surfaces of the material resemble a fine compact limestone.

The horizons, or beds, containing the ore often end abruptly only to reappear again at short distances away ; they do not keep to a definite 'line' in the clay. Such breaks or interruptions in the occurrence of the ore are shown by the repeated remains of old pits and workings found in various parts of East Sussex and Kent. It would seem that the early workers on 'losing' the ore at one point, would move on for about 50 to 100 yards and begin again with trial holes and pits.

Both types of ironstone, nodular and tabular, can be well seen in the banks and bed of a stream in Crowhurst Park (Sussex) about 250 yards from the south entrance, near Green Street. A complete chemical analysis of the material from this locality is given in an earlier paper [**1**, 1930, p. 51].

Mineralogically, the Wealden ore is a clay ironstone (siderite), and is in some respects like certain of the clay ironstones of the North of England. Thin sections of the rock show it to have a semi-opaque groundmass made up of limonite with the two rhombohedral carbonates siderite and calcite. Embedded in this matrix are tiny detrital quartz grains and shell fragments ; gypsum, also, is often present. Chemical analyses [**1**] closely approximate to those given for the material from the North of England, the FeO content for both types of ore averaging about 40 per cent. Topley [**7**], in speaking of the Wealden ore in 1875, says : " I known of no complete analyses of the Wealden ironstone. The clay ironstone of the Wadhurst Clay at Ashburnham contains 35 per cent. of iron (according to an assay by Mr. R. Smith of the Metallurgical Laboratory of the Royal School of Mines), which is about the average percentage of Coal Measure clay ironstone." Again, Topley (quoting from " The Pick and Gad ") [**8**] continues : " The stone from which this iron was manufactured seems principally to have been a spathose ore, or an altered spathose ore, where the carbonate of iron has been converted into a hydrated peroxide. The percentage of this class of ore seems to be very good, some of which I tried, producing as much as fifty per cent., a fair average would seem to range from twenty-five per cent. to forty per cent."

M. A. Lower [**9**, 1854] thus refers to the Wealden iron :—" That *some* of the iron wrought here was of the first quality there can be no doubt. The Ashburnham iron, particularly, excelled in the quality of toughness, and I have been assured by smiths who have used it, that it was in no wise inferior to the Swedish metal, generally accounted the best in the world."

A possible theory of the origin of the clay ironstones of the Weald is that they were formed in swampy ground, and that the bulk of the iron was derived by precipitation by decaying vegetable matter. The fact that the ore is in the form of siderite (ferrous carbonate) would appear to show that it was formed in a reducing environment, and that the external part of the material has subsequently been oxidised to limonite.

(b.) Comparison with other Bedded Iron Ores.

It is of interest to examine the sequence of the utilization of other bedded iron ores in Britain.

The Carboniferous rocks of the Midlands and the North of England contain very large quantities of ironstone, particularly in the Middle Coal Measures. In Northumberland, ironstone was once worked in the Carboniferous Limestone and near the base of the Coal Measures. In other areas, ironstones are confined to the Lower and Middle Coal Measures, except in North Staffordshire where banded ironstones occur near the base of the Upper or—according to some authorities—at the top of the Middle Coal Measures [**10**].

During the early part of the 18th Century, with the substitution of coal for charcoal as a fuel, these Carboniferous ores became of great importance and up to about the middle of the last Century they provided practically the whole of our iron. But, it is interesting to note that though the clay ironstones of the Carboniferous superseded those of the Wealden, even they in turn have given place to the Mesozoic ores of the Midlands (Frodingham, Northampton and Rutland) and Cleveland. In 1937, for example, out of 14,214,995 tons of ironstone raised in Britain, only 178,645 tons were obtained from the Carboniferous.

Why was the reign of the Carboniferous ironstones so comparatively short? The iron content of the North of England material reaches 40 per cent. and over, whereas in the case of the Mesozoic ores this only amounts to about 30 per cent. of iron, a few reaching 40 per cent. and some falling as low as 20 per cent. But, the value of a rock as an iron ore depends to a large extent upon its general composition and behaviour when smelted, and not *solely* upon its percentage of iron. Thus, a rock with a high silica content and having little or no lime may be rejected under present-day practice as of little value owing to its refractory character. On the other hand, a rock containing a small amount of silica and much lime, along with the same proportion of iron, may constitute an important smelting ore [**10**]. It is these advantages which the Mesozoic ores have over the Carboniferous and, in general, also over the Wealden ores.

The importance of Mesozoic ironstones compared with hematite and all other iron ores of the United Kingdom is shown by the fact that over 90 per cent. of our iron ore output during the years 1937 and 1938 came from this source :—[1]

West Coast Hematite	6.3 per cent.
Jurassic Ironstones	90.8 ,,
Coal Measure Ironstones	1.2 ,,
Other Iron ores	1.7 ,,

(c.) Iron Cinders and Slags.

The cinders and slags found throughout the Wealden iron ore districts are of much interest and serve as one of the permanent records of the industry. There are two varieties :—1. Bloomery and Power Forge Cinder. 2. Blast Furnace Slage or "Silica Slag." Both forms are practically indestructible and yield undoubted evidence of the character of the deposits and districts in which the ore was worked. Being the hardest and most durable material in the Weald, both varieties have from earliest times been much used for road-making in Sussex and Kent ; even today many old Manor Houses and Estates in the Weald continue to make use of the slag for their roads and paths.

1. *Bloomery Cinder.* This is blue-black in colour, rounded or globular in shape, with a very smooth surface, very hard, and a specific gravity of 2.5 to 3.8. Bloomery cinder usually has a high iron content, sometimes well over 50 per cent. of the oxide. The following analysis made by H. Silvester, shows the high percentage of iron in the cinder :—

SiO_2	32.4 per cent.
Al_2O_3	7.1 ,,
FeO	53.4 ,,
MnO	1.8 ,,
CaO	3.2 ,,
MgO	1.3 ,,
	99.2 per cent.

In this connection extensive use was made of the cinder in the Forest of Dean for mixing with ore in some of the later blast furnaces. Furthermore, there is evidence that in the Weald it sometimes paid to re-work this material rather than to search for and dig a fresh mine. Frequently pieces of limestone, burnt or unburnt, accompany bloomery cinder. Although providing such an important memorial of the industry, very little study appears to have been given to this material. Dr. A. F. Hallimond[1] has briefly described a series of micro-sections of some Wealden iron cinders, and shows that in addition to magnetite, fayalite (orthosilicate of iron) is always present.

---

[1] Figures from Statistical Summary 1936-38 ; Mineral Industry, Imperial Institute, 1939.

2. *Blast Furnace Slag* (*Silica Slag*). This is much like bottle-glass and bears a resemblance to obsidian. In colour it is black, blue or green, and often exhibits these colours in the form of bands or rings. Unlike bloomery cinder, blast furnace slag is often vesicular and contains many air bubbles. The solid forms have a specific gravity of 2.8-3, while the vesicular variety is light in weight and quite brittle, its specific gravity averaging about 1.4. The iron content of blast furnace slag, again differing from bloomery cinder, is very small, rarely, if ever, reaching 2 per cent.

An analysis of the material, also by H. Silvester,[2] is given below : –

SiO_2	45.0	per cent.
Al_2O_3	20.0	,,
FeO	1.0	,,
MnO	2.9	,,
CaO	27.0	,,
MgO	4.1	,,
	100.0	per cent.

III. METHODS OF TREATING THE ORE.

The Weald was fortunate in possessing two important requisites for the treatment of the ore : (a) *Fuel*, in the form of charcoal for the furnaces, and (b) *Water Power*, to work the mill hammers and bellows.

The ore itself (called " Myne ") was extracted by means of bell-pitting ; this is a method of working an ore by upward underground excavation. The bell pits (or mine pits) were about 6 ft. in diameter at the surface and widened gradually towards the base. They were usually rather shallow, never more than about 20 ft. deep.

(a.) Fuel.

Ample timber to provide charcoal for the furnaces was available from very early times, practically the whole of Sussex and considerable portions of Kent and Surrey being covered by one great forest. It extended from the Kent Coast over north Sussex, through Surrey into Hampshire. The Saxon Chronicle of 893 gives the extent as 120 miles long from east to west and 30 miles wide. Except for its river valleys and a few well-known tracks along the scarps, the forest was probably almost inaccessible. It was called by the Britons " Coit Andred," from its vast extent, and by the Saxons " Andradswald." Even at the present day the forests and woods of the Weald are the most abundant in England, and their great extent was an important factor in the development of the industry.

With the arrival of the Saxons a more rapid opening-up of the forest took place, and in this connection it is interesting to note the place names in the areas : for example, the dense portions of the forest were known as " hursts " and " charts." In East Sussex alone there are over 150 place-names ending in

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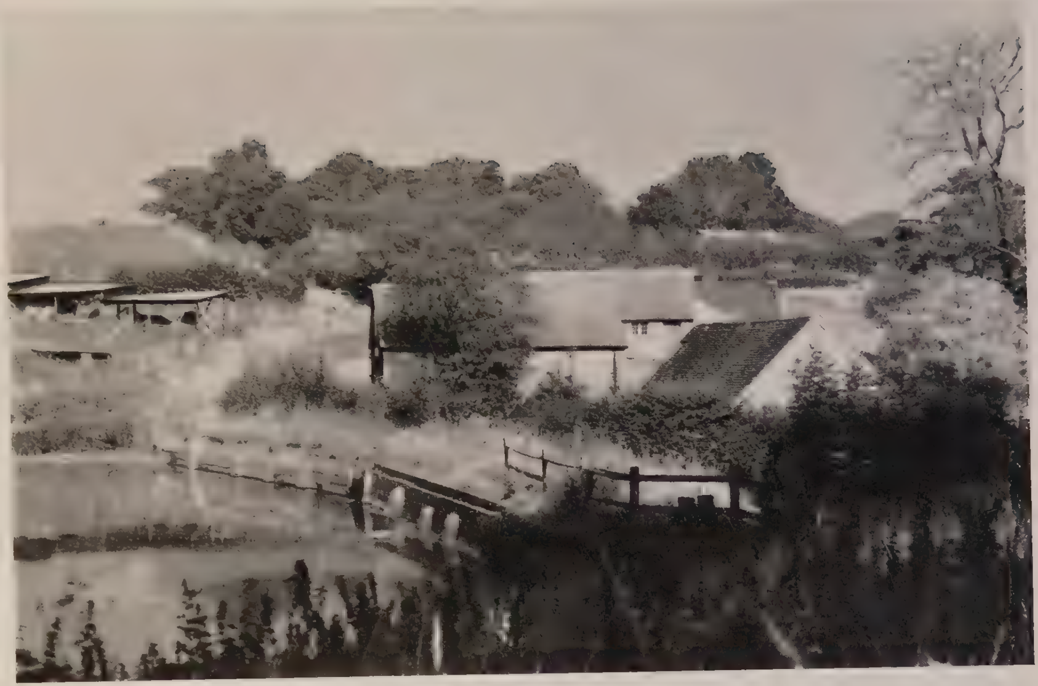
[1] See E. Straker, " Wealden Iron." 1931, p. 100.

[2] Both analyses taken from E. Straker, " Wealden Iron." 1931.



[Photo A. J. Bull.

HAMMER POND, DAM, AND FURNACE BUILDINGS, SCARLETS (COWDEN PARISH), SUSSEX.

[To face p. 8.

"hurst," and in Surrey 36 per cent. have terminations like "wood," "holt," "ley" and "den" [12].

During the greatest development of the industry, i.e., in the 16th Century, the amount of wood consumed was immense. Some idea of the rate of this consumption can be seen from the following examples. The furnaces of Sheffield and Worth (both in Sussex) alone used 2,175,000 cubic feet of timber during the years 1547-1549 [13]. At Ashburnham, 13 tons of pig-iron required 100 cords of wood [14], while at Lamberhurst the production of 5 tons of iron per week meant the consumption of 200,000 cords of wood annually (or 500,000 tons—a cord being equal to 2½ tons). In the 17th Century, of 140 forges in Sussex, each furnace consumed over 5 tons of charcoal per week.

Moreover, not only was the Weald able to supply all the wood-fuel for the iron industry, but it also supplied a large quantity to the Netherlands, Picardy and Normandy. The wood was shipped from Winchelsea by Flemish merchants, and though at no time did this town compare in size and importance with other East Coast ports, its position at the natural outlet of the Weald made it the greatest exporter of timber in England throughout the Middle Ages [15]. Small quantities of timber were also exported from the Medway.

Towards the close of the 16th Century, however, rapid and systematic destruction of the forests began. In 1577 much of the Forest of Kent had been cleared, and clearing continued steadily up to 1724. In the Forest of Dean where similar ironstone to that of the Weald had been mined, charcoal burners became a public nuisance, and as a result, a law was passed in 1558 prohibiting the felling of trees "to make coals for burning iron." This law, however, did not affect the Weald which was exempted.

The serious view which was taken by so many observers respecting the enormous consumption of wood, is expressed in some lines in *Poly-Olbion* by Michael Drayton (1612, the 17th song), as follows :—

> "Under the axe's stroke, fetched many a grievous groan.
> When as the anvil's weight, and hammer's dreadful sound,
> Even rent the hollow woods and shook the queachy ground."
>
> * * * * * * * *
>
> * * * * * * * *
>
> "Jove's oak, the warlike ash, veined elm, the softer beech,
> Short hazel, maple plain, light asp, the bending wych,
> Tough holly, and smooth birch, must altogether burn ;
> What should the builder serve, supplies the forger's turn,
> When under public good, base private gain takes hold,
> And we, poor woeful woods, to ruin lastly sold."

However, at the end of the 18th Century large wooded areas still remained in the Weald, as for example at St. Leonards, Ashdown, Goudhurst, Cranbrook and Ticehurst. It is perhaps not generally realised that Sussex, even today, contains a larger proportion of woodland than any other county in England. Thus it will be seen the decline and close of the Wealden industry was by no means due solely to the exhaustion of woods as has so often been claimed.

Charcoal and Charcoal-Burning. As the two industries, iron and charcoal, were so obviously dependent on each other for their existence, a note on charcoal and the charcoal-burning industry—now itself almost extinct—is given below.

Charcoal is impure carbon which results from the decomposition of vegetable matter by heat without free access to air.

Up to the end of the 18th Century, charcoal was prepared in the Weald entirely by "burning-in-piles." Logs or branches of oak and other trees were cut into 3 ft. lengths and piled into a 6 ft.-high heap or stack built on a hearth. The wood was then covered with turf and ashes to limit the entrance of air to that required for the process. The heap was protected from the wind by canvas-sheeting or sometimes by a screen of bracken about 10 ft. high. The heap was then fired at several openings left near the bottom, and a draught of air induced by leaving a hole at the top. Later, this hole was covered, and on the flame penetrating the heap entirely, the lower holes were also closed. When the mass cooled, charcoal remained, the heap itself being reduced in height to about 3-4 feet.

The process of **retorting** was introduced about the year 1805, the first retorts being erected near Petworth, Sussex. The Rev. Arthur Young,[1] in 1808, wrote : " This ingenious mode has been suggested to Government, by the Bishop of Llandaff, of making the charcoal in iron cylinders, of such a construction as effectually to exclude the air, and to preserve all the tar acid which is extracted from the wood in the course of burning."

Modern methods of charcoal manufacture employ somewhat elaborate retorting plant in order to recover the volatile constituents. The pattern of the plant differs according to the class of wood used. From hard woods, charcoal, wood alcohol, acetic acid and tar are recovered ; soft woods yield charcoal, turpentine, wood-tar oils and tar. It is of interest to note that the charcoal produced by the primitive method was a denser product than that made under later conditions, and, in consequence, was better suited for the iron ore industry.

The charcoal-burner (a " Colyer " as he was called) was a hardy type of man whose methods remained unchanged for centuries. His calling necessitated his living for weeks at a time beside his fire in the woods, usually in a small clearing far removed from roads or even footpaths and during all seasons and weather. His hut generally consisted of a circular arrangement of poles which met together at the top, and was made rainproof by a covering of turf.

Despite the closing-down of the iron ore industry, charcoal-burners continued their calling for a number of years afterwards and played an important role in the Weald, this time in the hop gardens. The hop driers at one period much preferred charcoal for their kilns, and thus the burner began a further period of useful activity. Now, like its early associate, the charcoal industry of the Weald has itself become almost, if not entirely, extinct.

(b.) Water Power.

It is noticeable that practically all the centres of the Wealden iron industry were situated in the upper courses of the rivers, and, as the drainage of the Weald is radial, their sources are consequently located in the centre of the Hastings Sands areas. (See Map, Fig. 1). The chief rivers serving the industry were the Arun, Adur, Ouse, Cuckmere, Ashburn, Brede, Rother, Teise and the Medway. They are all somewhat narrow and relatively swift, and this, together with their many tributaries, made them particularly suitable to supply the water-power needed for the mill-hammers and bellows.

Two ponds were generally required at each foundry, one for the blast at the furnace and the other for working the hammer at the forge, Thus, ironworkers requiring large quantities of water with as great a head as possible, selected where possible valleys with a steep gradient, and nearby rivers and streams were made to meet at certain collecting points. So assembled, the waters were impounded by building dams across the valley, and immediately below the dam a large water-wheel was placed.

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[1] " General View of the Agriculture of the County of Sussex," 1808, p. 432.

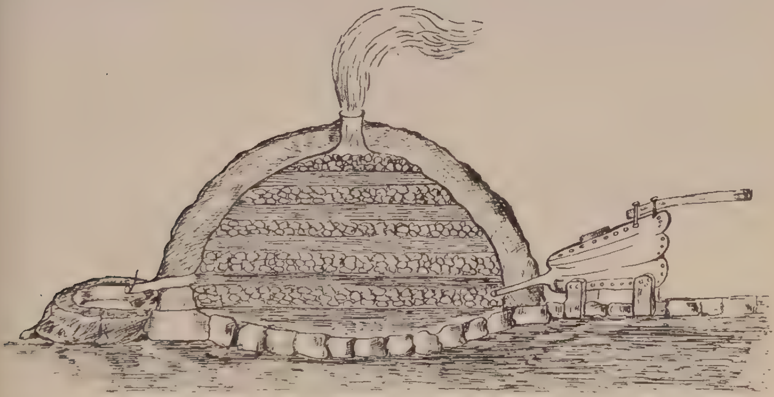
[Photo A. J. Bull.

HAMMER POND, IN DEEPLY-CUT VALLEY IN ASHDOWN SAND, SCARLETS, SUSSEX.

[To face p. 10.

Plate 4, A, shows the remains of a water-wheel at Scarlets, Sussex.[1] This has a diameter of about 19 ft., and immediately behind the wheel is the wall of the dam. I am unable to give the age of this wheel, or to say whether it actually existed during the closing years of the industry. Nevertheless, it offers an excellent example of the type and character of the water-wheels which were in use at that period.

The gathering grounds or collecting points of the waters referred to above constitute the common and well-known Hammer Ponds of the Weald, which today remain as one of the chief relics of the iron-works. Scattered throughout the woods, some of the smaller ponds are now much covered-in by vegetation and are sometimes almost hidden from view, while others form large and picturesque meres like those for example at Knepps Castle (Shipley) and Park Dale (near Battle) in Sussex, and at Furnace Mill, Cowden, in Kent.



[*Drawing by S. Money.*

FIG 2.—A BLOOMERY ; SKETCH SECTION.

(c.) Bloomeries and Furnaces.

In primitive times iron was always obtained in a malleable form direct from the ore : this is known as the Direct or Bloomery Process. Modern production involves a method in which Cast Iron is first obtained, and is termed the Indirect or Blast Furnace Process.

The Direct Process. The primitive furnaces which used the direct process were called bloomeries. These were built on a circular floor or hearth made of sandstone or brickwork. Upon this floor alternate layers of charcoal and ore were placed in the form of a conical or beehive-shaped heap, the whole being covered by a thick layer of clay. Hand or foot bellows were inserted into the lowermost layers of charcoal and ore in order to provide the blast. The metal collected as a spongy or pasty mass at the bottom of the bloomery and an outlet was made at the side to permit of the removal of slag or cinders (Fig. 2).

These masses were called "blooms." Bloom—a word derived from the Saxon "*Bloma*," meaning a lump—is rounded or oval in shape and is very vesicular or spongy in character. Though we have no accurate knowledge of the weight of a bloom, it seems to have varied from 50 lbs. to at least 150 lbs.; Rogers [5, p. 170] gives the general weight as 108 lbs. The blooms were beaten into shape by hammers which weighed from 1,200 to 2,500 lbs. and were worked by a large wheel turned by a stream of water. Two excellent, though small, examples of a bloom can be seen in the Metallurgical Department of the Royal School of Mines, London. One specimen shows the spongy material as taken direct from the bloomery, the other, after being partly forged and beaten. (Pl. 4, B).

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[1] Scarlets, though in Sussex, is in the parish of Cowden, *Kent*, and lies about 1½ miles west of Cowden Church.

In the early days production must have been a long and laborious business; for example, at the beginning of the 15th Century it is said that a single bloomery could produce no more than two tons of iron per week !

John Percy, the eminent authority of the last century on Iron and Steel, considered that the method then employed closely resembled—perhaps was identical with—the Catalan Process first used in the French Pyrenees in 1293 and which is still employed there. A Catalan forge consists essentially of a furnace, a blowing machine (called the trompe), and a heavy hammer ; the forge is erected in a locality where a fall of water from 11 to 12 ft. at least may be secured. The fuel is invariably charcoal.

"The Roman method has been pronounced very imperfect, because the refuse slags contain a large percentage of iron. Yet the slags produced by the Catalan process are always of necessity equally rich in iron ; and so are those formed in the modern South-Welsh charcoal finery process . . . . which until recently were thrown away, or used to mend roads. That the old slags should have become valuable as a source of iron . . . . does not indicate that the Roman method of extraction of iron from its ores, sometimes erroneously termed *smelting*, was less perfect, *qua* method, than the modern process of converting pig-iron into bar iron. They did by one process, according to the *direct method*, what we now effect by two ; and the slag which they produced should be compared not with our blast-furnace cinder, but especially with our finery, tap, and flue cinders" [6, p. 876].

The Indirect Process. From the 15th Century onwards blast furnaces were introduced. These were built of brick or sandstone, about 24 ft. square and 30 ft. high and having the form of a truncated cone. Alternate supplies of charcoal and ore were tipped into the top of the furnace, the blast entering by tubes or pipes at the side (Fig. 3). Inside, was an oval-shaped cavity lined with sandstone, and near to the mouth of the furnace a bed was prepared into which the cast iron was drawn off into moulds. These were called "Sows" if over 100 lbs. each, and "Pigs" if under that weight.

H. Powle [11[1]] gives a description of the processes adopted in 1678 in the Forest of Dean which so closely resembled those in the Weald. "Behind the furnaces are placed two huge pairs of bellows whose noses [nozzles] meet at a little hole near the bottom. These are compressed together by certain buttons placed on the axis of a very large wheel which is turned by water, in the manner of an overshot-mill. As soon as these buttons are slid off, the bellows are raised again by the counter-poise of weights ; whereby they are made to play alternately, the one giving its blast all the time the other is rising."

Once a furnace was lit, provided the hearth was of good stone, it could be kept burning for 40 weeks, the blowing period being calculated in "foundays" of six days each. The cinder-like scum in the furnace rose to the top of the molten metal and was drawn off from time to time and stacked into heaps.

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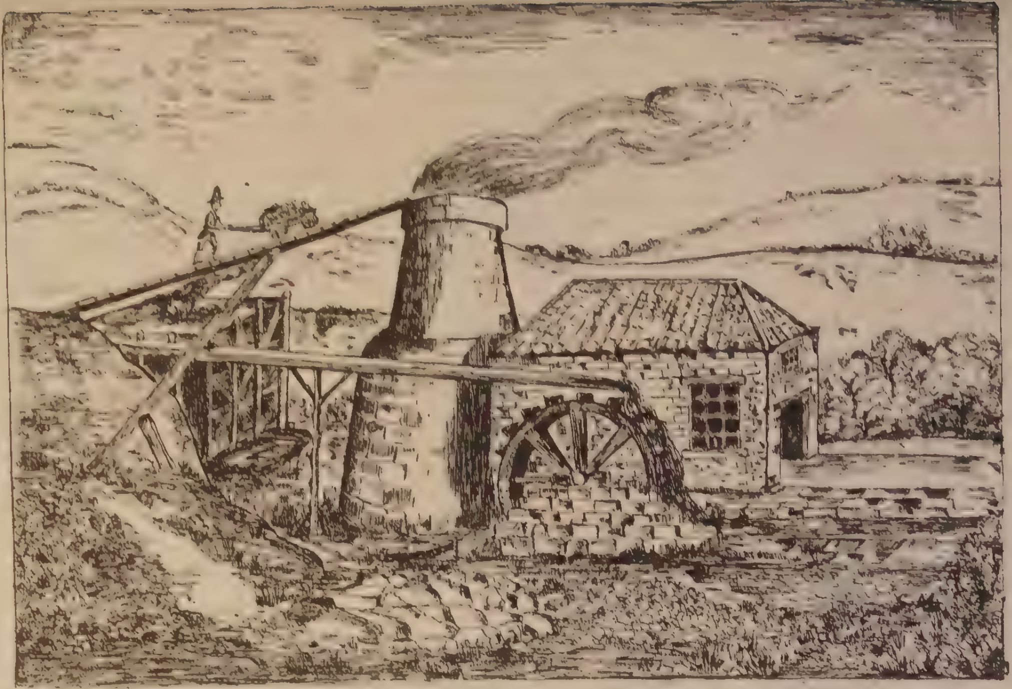
[1] See also W. Topley [7, p. 343].



[*Drawing by S. Money (after " Edgar Allen News," Oct., 1942*).

FIG. 3.—AN OLD SUSSEX IRON FURNACE.

At the present time there are many varieties and alloys of iron. Previous to 1860, and therefore during the time of the Wealden industry, three varieties only were known :—

1. *Wrought Iron* : Slag-bearing, very malleable and containing 0.25 to 0.3 per cent. carbon.
2. *Steel* : Intermediate between wrought and cast iron, the carbon-content ranging from 0.1 to 1.5 per cent. ; malleable and capable of being hardened by sudden cooling or quenching, and of being tempered by reheating.
3. *Cast Iron* (*Pig Iron*) : not malleable and containing 2 to 4 per cent. carbon.

Of the above, the commonest variety was always *cast iron*. The date of the introduction of cast iron into England is conjectural : M. A. Lower is of opinion that it was made in Sussex about the year 1350 (see p. 2, *re* Burwash). It has been thought possible that cast iron may have been made unintentionally in very early times, by accidentally using too great a heat. If such, however, was the case, the use of the product would not have been understood, and, moreover, the method of re-converting it would not have been known. The earliest application of cast iron to foundry purposes took place on the Continent towards the end of the 15th Century and was introduced into England about 1500.

Steel. Comparatively little steel appears to have been made from Wealden iron, and that which was produced came mainly from the districts of Robertsbridge and Warbleton.

In Conclusion : The effects of such a wide change in ecomonic conditions has now resulted in the Weald reverting to its former agricultural pursuits, though it still retains beneath its surface much of the material which once proved so important industrially.

The growth and improved methods in the art of smelting have contributed very largely to the development of the use of ferrous metals and, perhaps, nowhere else in Britain can the stages in such a development be more closely followed than in the Weald. This link, though now broken by improved metallurgical processes and geological discoveries, was so skilfully forged in the past as to make the Wealden Iron Industry not only one of the earliest, but one of the most important in the life of our Nation.

The author wishes to express his best thanks to Professor H. H. Read, F.R.S., for assistance and guidance during the early stages of this work. To his colleagues, Mr. S. E. Coomber and Dr. G. D. Hobson, he is indebted for much useful discussion and criticism, and also to Dr. G. W. Himus particularly in connection with the sections on Fuels and Furnaces.

The author's thanks are also due to Dr. A. J. Bull for the excellent photographs which accompany this paper. Dr. Bull not only devoted much time and care to these illustrations, but gave the author valuable advice on the selection of the subjects.

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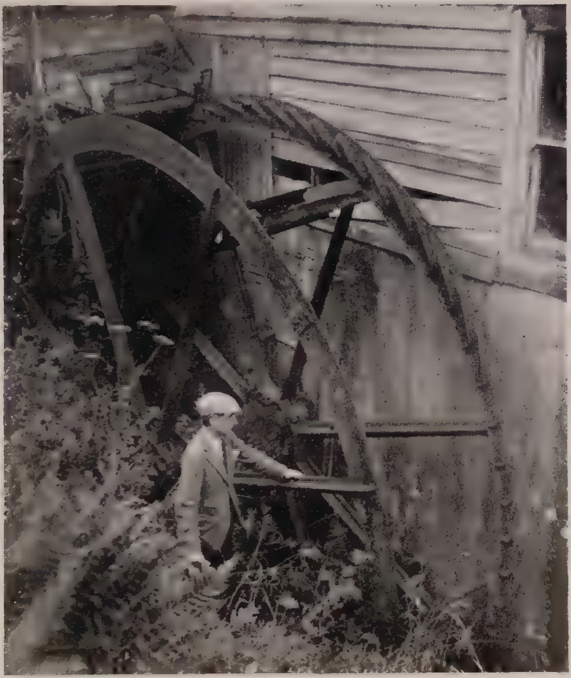
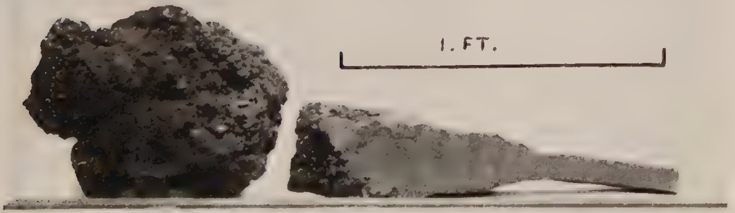


[*Photo A. J. Bull.*

A.—REMAINS OF WATER WHEEL, SCARLETS, SUSSEX.



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(From the "John Percy Collection," Royal School of Mines.)

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DISCUSSION.

Mr. S. H. Beaver : Mr. Sweeting's paper raises several interesting points. I wonder if 'reversion to agriculture' is quite the right expression to employ ? There are two possible objections, one being that in a forested area like the Weald there never was much agriculture, and so the cutting down of the timber opened up new land for farming ; the other is that it is feasible that agricultural operations were always relatively more important, in personnel employed, than iron-working. Perhaps Mr. Sweeting can say which of the two objections, if either, is correct ?

I should like to know if there is any evidence in the Weald of the existence of hill-side furnaces—corresponding to the 'boles' of Derbyshire and Yorkshire, for example—which made use of natural wind-blast, or whether furnaces have always been confined to valley bottom sites. And with regard to charcoal, what sort of wood was normally employed ? I have recently been reading literature on the early history of the Belgian iron industry, in which the importance of beech-wood for charcoal is stressed ; beech is regarded, I believe, as one of the best producers of charcoal, but this tree can hardly have been very abundant as a natural constituent of the Wealden forests. Mr. Sweeting's remarks and pictures relating to the actual burning operation and its similarity to the early coke-making process of Darby remind me of an interesting survival which can still be seen in the Black Country—a cold-blast furnace not far from Dudley, which is fed with coke made in heaps in the open, in almost exactly the same fashion as in Darby's first efforts at Coalbrookdale two hundred years ago.

One last point. The reference to the sending of Wealden ore to the Black Country in 1857 is most interesting. It was just at this period that, with the local Coal Measures ironstones becoming increasingly uneconomic to work, Midland ironmasters were seeking all kinds of new raw materials ; they began to use Northamptonshire stone (without in the least liking it !) in some quantity ; but the importation of Wealden ironstone must surely have been a very short-lived phase.

Mr. T. Deans : Mr. Sweeting's paper raises many points which interest me, as I have recently been studying the literature on primitive iron smelting in tropical Africa, where methods directly comparable with the earlier phase of the Wealden industry are in use today. In describing the bloomery process in the Weald it is usual to refer to the use of bellows, but elsewhere these have not always been used. Natural draught furnaces built on hillsides to catch the prevailing winds have been mentioned by a previous speaker, and certain African tribes, although using bellows for the subsequent forging operations, smelt the ore in a conical furnace 8 to 12 feet in height with numerous tuyeres at the base which operates entirely on natural draught, although it may be situated in a sheltered spot. In these furnaces smelting is rather slow, but the bloom obtained is comparable in size with Weald blooms. Is there any evidence of smelting in the Weald without the aid of bellows or blowing machines ?

Perhaps the most interesting feature of the Wealden industry, however, was the early introduction of iron casting. This involved working at considerably higher temperatures than previously, and for the first time made possible the extraction of all the iron from the ore. Wealden ore was easily smelted in the bloomery, as the siderite when calcined became porous and the siliceous impurities rendered it self-fluxing, but a quantity of iron roughly equal to the weight of silica in the charge was inevitably lost in the slag. At the higher temperature necessary for the production of cast iron, the silica can be slagged off by lime, without any loss of iron. Was smelting with the addition of lime (as chalk, limestone or perhaps calcareous ironstone) introduced in the Weald simultaneously with iron casting, or when was this great technical advance made ?

Miss Emily Dix added her appreciation of Mr. Sweeting's paper to those of previous speakers. She said that she was interested in the origin of the iron ore and enquired whether any plant remains had been found associated with, or in, the nodules of siderite similar to those found in the ironstone nodules of the Carboniferous. She also asked whether any pyrite had been found in association with the siderite.

Mr. F. H. Edmunds : Although unable to hear Mr. Sweeting deliver his most interesting and useful paper, I have had an opportunity of reading his manuscript. From time to time the question is raised as to the economic possibilities of again working the Wealden iron ore. In point of fact the useable reserves of iron ore in the Weald are, in present circumstances, negligible. The ore, which occurs in thin beds, can only be excavated together with a large amount of clay and shale. Its constitution is very variable, and in general it is of poor quality. Both quality and mode of occurrence are illustrated by the record of the Snape Wood mine, near Wadhurst, from which ore was exported to Staffordshire for a short time (1857-1858). An analysis made by Messrs. R. R. Tatlock and Thompson in 1908 (*see* J. W. Gregory, " Report . . . . on the Prospects of Iron Mining and Smelting in the Neighbourhood of Sheffield Park, Sussex," 1908 ; privately printed) showed the following :—FeO, 30.42% ; Fe_2O_3, 10.10 ; SiO_2, 26.10 ; P_2O_5, 0.49 ; CaO, 0.86 ; SO_3, 0.06. These figures show about 30.66% of metallic iron, but the high percentages of SiO_2 and P_2O_5 would prevent the use of this stone as an ore today, and undoubtedly militated against its continued use in Staffordshire. At this mine two beds were worked, one up to 2 ft. thick. Both were irregular in occurrence, sometimes dying out completely. The roof was bad and required timbering. Other analyses give higher percentages of metallic iron, but all show low grade ore.

Nowhere in the Weald are there likely to be occurrences of ore in large quantities, nor in my opinion is it likely that there ever have been. The industry used annually very small quantities of ore, collected from widespread localities, and it seems doubtful whether conditions of smoke-laden skies ever existed. On account of the need for water provided by pen ponds, works were tucked away in side valleys ; they were, moreover, of small size, some producing no more than 50 tons of iron a year, and by far the largest, at Ashburnham, only producing 350 tons annually. The Wealden iron industry, though of great importance during its heyday, was never more than a very small affair compared with modern standards.

Dr. A. F. Hallimond : I greatly regret my unavoidable absence from the reading of this paper. The ancient slags offer an interesting and as yet little explored field for investigation. Even if they do not always offer a general means of dating the old iron furnaces, there are certainly wide variations in the slags from different processes ; caution must, however, always be observed in dealing with isolated specimens, since they may represent unsuccessful or non-typical products. An interesting point, upon which the dated sites may ultimately throw further light, is the question of the presence of lime in certain slags ; lime often has the effect of lowering the iron-content of the slag, and may have been beneficial even in the early small furnaces. Some ironstones have a natural lime-content, and it would be interesting to have further evidence whether any benefit resulted from their use, and, if so, whether lime was ever purposely added in the usually lime-free processes. I look forward to the pleasure of reading the paper on its appearance in print.

Mr. A. S. Kennard : Through the kindness of Mr. Sweeting, I have seen the MS. of his paper. One often sees the statement that the Wealden woods were cut down to make charcoal for smelting the ironstone. This is not correct. The trees were certainly " thrown," i.e., cut down at the roots and leaving no stub, but the " timber " was never used for charcoal. That was made from " top and lop " and from the smaller " poles," or what is to this day called " charcoal wood "; for charcoal in diminishing quantities is still used for hop drying. The timber was sent to the shipbuilding ports such as Chatham, Rye and Hastings. Enormous quantities of timber were required for the Navy at Chatham. That most famous of all ships, H.M.S. Victory, was built and rebuilt at Chatham. Many thousands of trees " rough hewn " were also used in the construction of " sea walls," many of which were built in the Stuart period and thousands of trees were sent at the beginning of last century from the neighbourhood of Cranbrook for the Dymchurch Wall, immortalized by Kipling.

There is a tradition at Cranbrook that the ironstone for the railings of St. Paul's was dug at Blower's Hole in that parish and smelted at Lamberhurst. This is now doubted, but as a firm believer in these old traditions, I still believe there is a large element of truth in the story, though possibly the true version should be " some of the stone," for it was a very big job and the casting may have been done at several furnaces. The " toll " for " cannon " was on all the tollgate tables round Cranbrook until their abolition in the seventies of the last Century.

Dr. S. W. Smith : The question has been raised as to why the Bronze Age preceded the Iron Age. A possible explanation is furnished by the fact that iron, in the malleable and relatively pure state, can only be brought into the molten state at very high temperatures—exceeding 1527° C, the melting point of pure iron. Iron, therefore, as produced in the form of " blooms " by the reduction of iron ores in primitive furnaces was never seen in the molten condition as were the metals of lower melting point, such as lead, tin and even copper, silver and gold. It is conceivable, therefore, that the discovery that these unpromising " blooms " of spongy metal, intermixed with slaggy material, could be rendered malleable and useful by repeated forging at a red heat, came later in the history of metallurgy. The actual melting of such material, or rather of steel produced from it by 'cementation' in powdered charcoal, was not effected until Huntsman first made crucible steel at Sheffield in 1730-1735 by melting 'cemented' steel in refractory crucibles with a forced draught.

Some time in the 14th Century, however, it had been discovered that a fluid product, which we now know as "pig" or cast iron, could be produced in these small furnaces by prolonging the operation and carrying it out at higher temperatures than those hitherto employed. This marks what has been spoken of in the discussion as the "transition" in the industry, but actually there was no transition because this fluid product was a distinct product and could only be used for making castings in which the property of malleability is lacking. So, in all probability, the Sussex iron industry, while it lasted, produced these two distinct products—wrought or hammer-forged iron, used either as such or for conversion to steel by 'cementation,' and cast-iron which could be cast in moulds for making cannon and other articles. It was not until Cort introduced the process of 'Puddling' in 1784 that "pig" or cast iron—melting in the region of 1100° C—was used on any considerable scale for the production of malleable or "wrought" iron, and then only in the form of "blooms" such as those originally produced direct in the primitive furnaces. Nasmyth's steam hammer contributed to easing the operations by which these "blooms" were forged and welded together for industrial purposes. The subsequent discovery in 1856 by Bessemer that molten pig iron could be converted to nearly pure iron or "mild steel" by 'blowing' fine jets of air through it and that, moreover, the intense heat produced by the actual combustion of the carbon and other impurities contained in it was sufficient to maintain this relatively pure iron in a molten condition, was the foundation of the Steel Age.

Viewed in relation to modern large scale production it is an interesting point as to whether the Wealden iron industry can be regarded as ever having exceeded what may be termed a "rural industry," although, undoubtedly a widespread one.

Dr. L. J. Spencer : During the reading of his most interesting paper the author hovered between two distinct pronunciations of the word siderite. Besides having different pronunciations, this word has also many different meanings : the Oxford Dictionary lists no less than eight, with quotations relating to lodestone (=magnetite or maghemite) dating from 1579. Between 1790 and 1811 the name was applied to four other minerals (pharmacosiderite, blue quartz, lazulite, and hornblende), while its application to iron carbonate dates only from 1845. It is also the name of a plant (iron-wort). But its most appropriate application is to meteoritic iron, which supplied the first iron used by man. A connexion between the names of falling stars (thunderbolts or meteorites) and iron has been traced in some ancient languages ; and it is possible that there is some connexion between the Greek σίδηρος (*sidéros*, iron) and the Latin *sidus, sideris* (star).

A better and unambiguous name, which has been applied to no other mineral but iron carbonate, is chalybite. This name was given by Glocker in 1847 from the Greek χάλυβος (chalybos, steel), because the mineral contains iron and carbon. Dana in the 4th edition (1854) of his "System of Mineralogy" used the name chalybite, but in his 5th edition (1868) changed to siderite on the grounds of priority, overlooking the fact that this name was very much preoccupied.

In associating himself with the congratulations of the previous speakers, **Dr. Vernon Wilson** suggested that the author would greatly enhance the value of his excellent historical survey by bringing the geological aspects of it up to date so far as possible. He thought this might be done quite concisely in the form of :—(a) A map of the outcrop of the ore showing also the worked-out areas; (b) a stratum contour diagram of the top of the ore bed; (c) an isopachyte map of the strata comprising the overburden. He also hoped the author would devote some further discussion on the prospects of, or objections to, any further exploitation of the ore.

Mr. A. Wrigley thought that the dates given by the author for the introduction of iron casting in Sussex were important, because they marked a major epoch of metallurgy. In the excellent Huxley memorial lecture of 1912 delivered to the Anthropological Institute by Prof. Gowland, it was emphasized that the melting and casting of iron are comparatively modern processes, which may lead to a misconception of all the earlier treatment of that metal, which was to produce malleable iron without fusion.

In a primitive hill-top hearth with a wind draught, it is quite easy to produce malleable iron from the common oxide ores mixed with charcoal, so that one wonders why copper and bronze ages should have preceded the iron age as certainly they did. The explanation is that copper and bronze, although they require greater heat for their reduction than iron, can be melted and cast at a far lower temperature. Bronze tools and weapons *were* cast, as we know from the many stone moulds for them which are extant; their edges were hardened and tempered by hammering. Remember that the Romans managed to shave with bronze razors. The early bronze sword was a better weapon than one of malleable iron—the Celtic iron weapons were bent and buckled upon the Roman shields. A critical date, very difficult to be settled, is for the introduction of steel.

The Author: In reply to Mr. Beaver, I am of the opinion that agriculture was always the chief industry of the Weald—excepting of course during the prosperous years of the iron trade. During this period there is evidence that there was a big transfer of labour from agricultural work to that of iron production; moreover, of course, it is quite likely that an influx of workers also came from other mining areas.

There is no evidence in the Weald of the existence of hill-side furnaces; they were always situated on low ground in the bottom of valleys. The kind of wood employed in making charcoal—a reference to which was also made by Mr. Kennard—has always been a debatable point. Oak, and in lesser quantities, ash and elm are generally considered to have been the chief kinds of timber used. Yet, at times it would appear that many other trees were used for charcoal. (See, for example, Michael Drayton, p. 9).

Mr. Deans draws some comparisons of the smelting methods employed in tropical Africa with those employed in the early days of the Wealden industry. There is no evidence of smelting in the Weald without the aid of bellows or blowing machines; the position of the furnaces is referred to in an answer to the previous speaker.

With regard to the question whether smelting with the addition of lime was introduced in the Weald simultaneously with iron casting, I am of opinion that this may have taken place much earlier. For example, fragments of limestone or calcareous material—burnt and unburnt—are sometimes found accompanying the ancient bloomery cinder; I have found such material myself. In some areas, as at Ashburnham, thin beds of limestone actually occur in close association with the ironstone. It is possible therefore, that in such cases the limestone was found to be a ready and easy means in helping to smelt the ore.

In reply to the enquiry by Miss Dix, regarding plant remains in the ironstone nodules, I have never seen plants or other fossil remains in this material, although I have always kept a careful "look-out" for them. Similarly, no pyrite has been found associated with the siderite, an association which is certainly common in the ironstone nodules of the Carboniferous of the North of England and elsewhere.

I thank Mr. Edmunds for his interesting comments, but I should like to point out that I did not wish to suggest that the scale on which the Wealden iron was produced, was in any way comparable with that of the present day industry.

Dr. Spencer's remarks on the pronunciation and use of the words siderite and chalybite are very interesting. It is unfortunate that the word *Chalybite*, which obviously has priority over Siderite, should drop out of use. For a number of years past, mineralogists when referring to iron carbonate have tended to ignore entirely the use of the word chalybite. If there are sound reasons for retaining *both* words—as there appear to be—could they not be used as, e.g., chalybite (siderite) *or* siderite (chalybite)?

In reply to Dr. Vernon Wilson: in such lenticular and "interrupted" occurrences of the ironstone—which, moreover, was mined by bell-pitting—it is not possible for worked-out areas of the ore to be plotted. Similarly, there is insufficient data available of the height above O.D. of the basal beds containing the ironstone to enable the construction of a stratum contour diagram to be made. The question concerning future possibilities of further exploitation of Wealden ore, has been answered by a previous contributor (Mr. F. H. Edmunds).

The reference made by Mr. Wrigley and other speakers to the dating of the Iron Age is a matter of much interest and one which has always been conjectural with archaeologists and metallurgists. That iron was well-known and valued in primitive times (possibly before copper), there can be little doubt. To fix a time-period for the first application of this metal, however, is a difficult matter. One point worthy of note is the lower resistance to weathering and oxidation of iron compared with bronze, and the reduced likelihood of the survival of relics, or traces, of early implements. In this connection I quote some relevant remarks by T. Turner in "*The Metallurgy of Iron*" (1915), p. 2:—"That iron rusts in moist air and that this process of oxidation gradually proceeds throughout the whole mass of metal is well known. On the other hand, flint is unaltered by atmospheric influences, while bronze is, under favourable conditions, very slowly attacked. If implements of these three materials were buried in the earth and allowed to remain for a lengthened period, it is quite possible that the flint would remain practically unaltered, and the bronze be little changed, while the iron would be converted into a brown mass of hydrated oxide, cementing together some pebbles; or even, if the drainage water contained vegetable matter, this cement might itself be washed away and nothing whatever remain to indicate that iron had been originally there."

I should like to thank Dr. A. F. Hallimond for his contribution and also Dr. S. W. Smith for his interesting metallurgical comments.

A NEW SECTION IN THE LOWER LONDON TERTIARIES NEAR WEST WICKHAM, KENT.

By G. W. HIMUS, Ph.D., F.G.S., and ALAN WOOD, Ph.D., F.G.S.

[*Received 8th September*, 1943.]
[*Read in abstract 6th November*, 1943.]

THE section is exposed in a cutting for a new road about three-quarters of a mile S.W. of West Wickham Station. The lower end of the cutting starts from the Addington Road at a point about 2 furlongs from the bottom of Corkscrew Hill and 1 furlong from Hawes Lane and extends approximately N.W. for a distance of 3 furlongs.

The strata exposed consist of Blackheath Beds, about 20 ft., and Woolwich and Reading Beds (obscured below by talus), 15 ft. It is probable that Thanet Sand is crossed at the lower end ; this is indicated on the map, Fig. 5. The section as measured was as follows :—

		Ft.	in.
	Soil, very thin .. .. about		3
Blackheath Beds, say 20ft.	Fine sand with flint pebbles and fragments of Chalk, possibly replacing laterally some of the previous beds	4	0
	Bed of small flint pebbles, sometimes cutting down into the bed below		1½
	Fine brown sand, thickening to north-west	4 to 6	0
	Pebble beds, with rolled flints, some white and weathered right through, others with a black surface. Cutting down sometimes 3 ft. into the beds below	3 to 6	0
	Clay silt with eroded top	1 to 2	0
	Bedded clay silt, passing into sandy silt with patches of rolled clay	1	4
	Brown, fine grained sand with fragments of *Cyrena* in lower portion	1	6
	"Shell-bed," mainly *Ostrea bellovacina* Lam. and *Cyrena* spp. (the latter dominant in the upper layers) converted into a hard stone	3	0
	Brown sand .. .. 1 ft. 6in. to	2	0
Woolwich and Reading Beds, 15ft.	Comminuted shells in sand		4
	Fine, brown sand, passing down into silt	2	0
	Silty clay, passing down into grey and brown clay	1	0
	Grey clay		4
	Comminuted shells		4
	Brown clay, passing down into grey clay with shells	1	6
	Shell-bed ; comminuted shells in clay	1	0
	Brown clayey silt, passing down into grey and brown variegated clay ; brown, bedded clay at base	3	3
	Comminuted shells in grey clay		9
	Brown and grey clay with tiny fragments of shells	5	0
	Remainder of section obscured by talus.		

Mr. A. G. Davis, who visited the section in 1942, when the rocks were less weathered, kindly furnished the following list of fossils from the Shell Bed, which includes several forms we did not find.

Ostrea bellovacina Lmk. (Common, but typical examples rare).
„ *tenera* J. Sowb. (Rare).
Cyrena (*Corbicula*) *cordata* Morris (frequent).
„ „ sp. Tumid form (frequent)
„ „ *tellinella* Férussac (frequent).
„ „ *cuneiformis* Férussac (common).
Melanopsis buccinoides Férussac (rare).
Tympanonotus funatus (Mantell) (common).
Melanatria inquinata Defrance (frequent).
Conopeum eocena (Busk) (frequent).

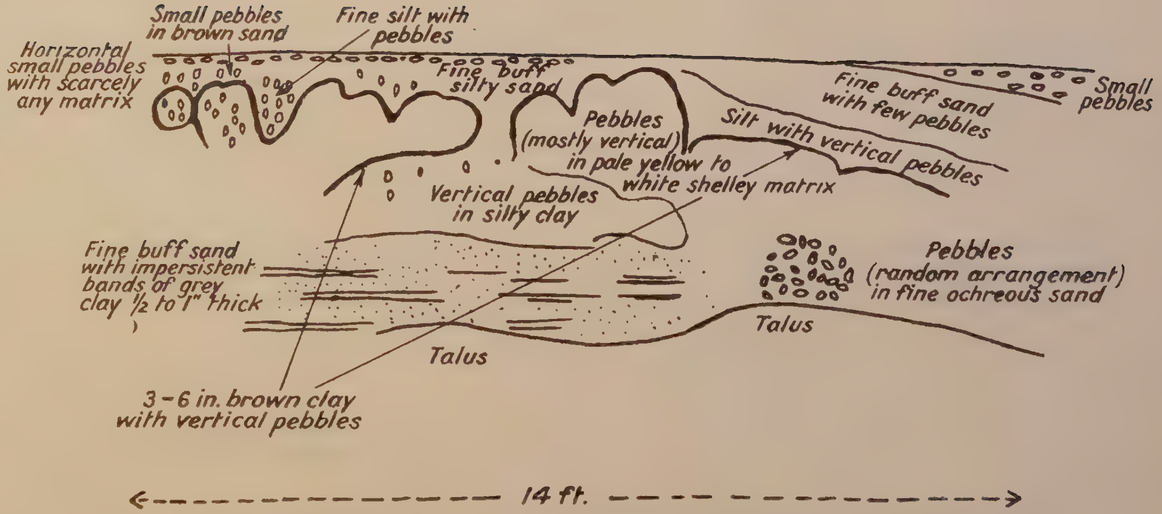
Small pebbles in brown sand
Fine silt with pebbles
Horizontal small pebbles with scarcely any matrix
Fine buff silty sand
Pebbles (mostly vertical) in pale yellow to white shelley matrix
Fine buff sand with few pebbles
Small pebbles
Silt with vertical pebbles
Vertical pebbles in silty clay
Fine buff sand with impersistent bands of grey clay ½ to 1" thick
Pebbles (random arrangement) in fine ochreous sand
Talus
Talus
3–6 in. brown clay with vertical pebbles
14 ft.

FIG. 4.—CALCAREOUS PATCHES IN THE BLACKHEATH BEDS IN ROAD-SECTION AT WEST WICKHAM, KENT.

A dip of 3° in a direction approximately N.W. was measured on the shell-bed in the Woolwich and Reading Beds; so far as we have been able to determine from our observations, the true dip would be 4° on a bearing 8° West of North.

The Blackheath Beds are very variable and the above section is only reliable for the beds actually measured. Probably the most striking feature seen in the road-cutting was the presence of extensive areas of pebbles in a white to pale yellow shelly matrix, which stood out in marked contrast to the (usually) buff to brown sandy and silty Blackheath Beds (Fig. 4). The light areas were almost completely surrounded by a rim of dark brown clay, some 2 to 3 or even 6 in. thick containing many flint pebbles. The majority of the pebbles in both the "light" areas and their clayey margins were arranged vertically. The shapes of the light areas preclude the idea that they were originally deposited thus; it seems more probable that they represent the residues of shell-banks which have suffered and are suffering from solution by percolating waters. The margin of "clay with flints" would thus be a residual deposit left after the dissolution of the shelly fragments. It was found that when treated with hydrochloric acid the white shelly matrix suffered a diminution of 60 per cent. by volume, leaving an orange to brown clayey or silty residue. The clay margin, on the other hand, under similar treatment lost only about 8 per cent. by volume, due mainly to the removal of iron, for the solution from the marginal deposit was coloured orange while that from the pale cores was scarcely tinged at all.

Large pieces of a conglomerate, consisting of Blackheath pebbles of various sizes with fragments and bands of *Ostrea* were also found; none were seen in situ. The conglomerate is rather "tender"; when broken, it fractures round the pebbles and never through them, but otherwise it resembles the well-known Hertfordshire 'Pudding-stone' rather closely.

Other New Exposures in the Neighbourhood.

Further information on the geology of the immediate neighbourhood was obtained from a number of temporary sections, mainly bomb-craters, and these have been used in constructing the sketch-map (Fig. 5).

Although no Thanet Sand is at present visible in the cutting, it is considered almost certain that a narrow belt of them must intervene between the Woolwich and Reading Beds and the river deposits which occupy the dry valley along which the Addington Road runs. Five feet of Thanet Sand of a light yellow colour, overlain by 2 ft. of brown hillwash, were seen in a trench-section to the south-west, leading from Sparrows Den. to the lower edge of Springpark Wood. To the north-east of the new road these beds were also exposed low down in the western bank of the large gravel pit on Tiepigs Lane. Farther to the south-west the outcrop of the Thanet Sand widens somewhat and forms a gentle slope rising from beneath the river deposits which occupy the bottom of the dry valley. Hillwash from these beds forms a very gentle concave slope merging imperceptibly into the alluvial flat.

The outcrop of the Woolwich and Reading Beds rises sharply in a concave curve, the slope becoming steeper towards the south-west. In Springpark Wood, bomb-holes show variegated clays with shelly fragments, enabling the upper boundary to be followed very accurately. A trench-section running for a distance of more than 300 yards from the sharp bend on Corkscrew Hill, roughly north eastward, showed variegated clay, sometimes with fragments of shells in its lower portion near Corkscrew Hill. Owing to the dip of the beds these were absent where the trench cut the new road section.

The incoming of the Blackheath Beds is marked by a distinct "step" on the hillside, caused at the new road-cutting by the oyster-bed. Here the step is at a height of 260 ft. O.D. On Corkscrew Hill the base of the Blackheath

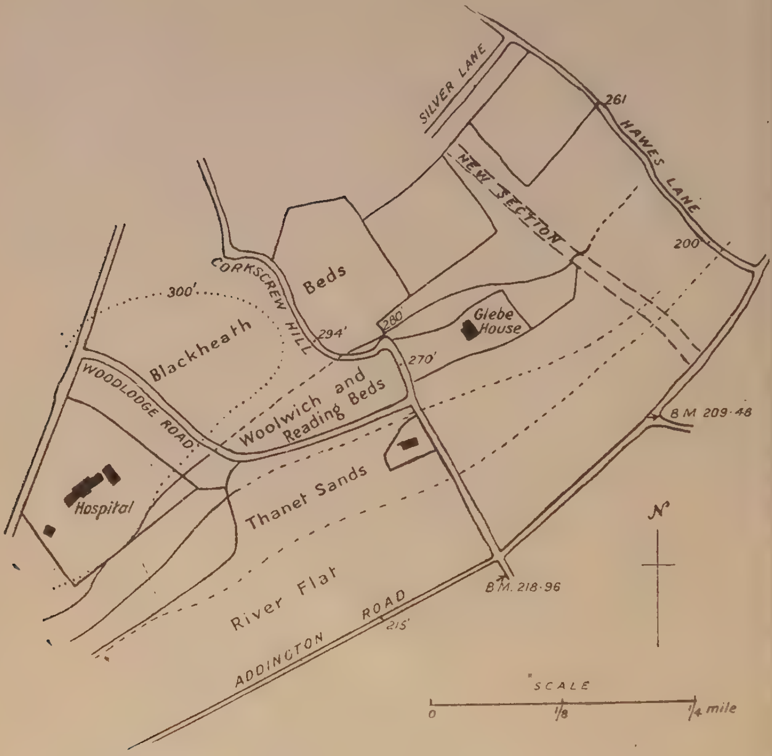

FIG. 5.—GEOLOGICAL SKETCH MAP OF DISTRICT S.W. OF WEST. WICKHAM. Boundary lines interrupted where uncertain.

Beds appears at 280 ft. Both these heights were deduced from observations made with an Abney level, from sights to points of known elevation. Farther to the south-west the base of the Blackheath Beds cuts the 300 ft. contour by the fence of the hospital in Springpark Wood. Traces of the oyster-bed were observed in the trench-section east of Corkscrew Hill, but no farther to the south-west. The Blackheath Beds form a sharp slope which flattens abruptly at the summit of the hill, and their outcrop extends over an area of flat ground to the north-west. London Clay appears to be absent or very thin over the area studied.

THE N.E. LANCASHIRE GROUP OF THE GEOLOGISTS' ASSOCIATION: TWENTY-ONE YEARS' RECORD.

By ARTHUR BRAY, M.Sc., Assoc. Inst. M.M.
(Hon. Jt. Secretary, N.E. Lancs. Group).

THE North East Lancashire Group came into being twenty-one years ago. Its beginnings were homely. In September, 1922, (Circular No. 251) it was announced that the Council of the Geologists' Association were prepared to consider the formation of local groups, especially in areas where members were not within easy reach of the lectures and field meetings, arranged from London. A little local propaganda was undertaken and contacts with persons likely to be interested were made. In a short time a group was formed of about eighteen members, all of whom were keen and many of whom knew the local geology in great detail.

At this time the Geological Survey was re-mapping the district, and the Millstone Grit (which figures so largely in the local geology) was being studied by Bisat, the Geological Survey, and other workers. The time was opportune, and professional and amateur geologists were at hand in a position to assist one another.

In those days no fixed meeting place was available. The Group met in private houses and after the lecture sat round the fire and talked of many things. The number attending the meetings was usually about twenty and lectures were given at members' houses in Accrington and Blackburn. Usually the lady of the house provided tea and at the homes of the mechanically-minded members the " Cat's Whisker " was tuned in and some of us listened in with headphones ; wireless sets were home-built in those days and loud speakers were only just being introduced. Finally the group progressed to holding meetings in the Blackburn Technical College (through the kindness of the College authorities and the Blackburn Education Committee), where the meetings have continued to be held. The Lancashire unit of the Geological Survey and the neighbouring universities have always been willing to provide us with lectures and some very fine discourses have been given, leading to lengthy discussions. In addition, unattached geologists have always been willing to give their services.

In the summer session field meetings are held and until travelling became restricted, they ranged as far afield as the Yorkshire Dales and the Lake District, in addition to more local excursions. In 1926 a Long Field Meeting of ten days' duration was arranged by the Geologists' Association and places of geological interest were visited in the area under the guidance of members of the Local Group and others.

With the beginning of the war and the consequent black-out things became more difficult. There was, however, only a slight falling off in attendances and new members replaced those who could not now reach Blackburn. The Group has continued in a healthy condition in spite of all difficulties. Full lecture and excursion syllabuses have been arranged, although some have been fixed up too late to be announced in the monthly circular from London.

The Group has not changed its officers much with the passage of time. With the exception of the year 1925-1926, when the writer acted, Mr. J. Ranson has been Group President continuously.

On Saturday, October 16th, 1943, the coming of age of the Group was celebrated by a Field Meeting led by Mrs. E. J. Harrop, to visit a water boring on Darwen Moors. Between thirty and forty members attended. The weather was not very favourable, but the full programme was carried out. Afterwards tea was served in the Kiosk in Sunnyhurst Park, Darwen. A letter from Professor H. H. Read, President of the Geologists' Association, was read wishing the Group every success and regretting that a member of the Council could not be present.

The President of the Group, Mr. J. Ranson, then reviewed the progress of the Group. He stated that it was the function of the Group to spread the love and understanding of geology. Over 200 lectures and field meetings had been held. The last twenty-one years had been very active in the publication of work on the local geology, but the Group could bring a great deal of information to the lay person who would be unlikely to read the original papers. In 1937 the Foulerton Award was presented to Mr. Ranson and Mrs. Harrop (née Wooff).

Mr. Ranson regretted the passing of many old members and welcomed the more recent new-comers. He hoped the Group would pass from strength to strength and that the spirit of good fellowship would continue. At the close of the meeting a vote of thanks was proposed to Mr. Ranson by Mr. Bray, who hoped that he would continue in office for a long time to come and enjoy long life and happiness.

THE ANNUAL REPORT OF THE COUNCIL OF THE GEOLOGISTS' ASSOCIATION FOR THE YEAR 1943.

[Adopted at the General Meeting on March 4th, 1944, as the Annual Report of the Association.]

THE numerical strength of the Association on December 31st, 1943, was as follows :—

Honorary Members	16
Ordinary Members :—	
Life Members (compounded)	112
Annual Subscribers	1016
	1144

During the year 58 new members were elected and the Association lost 31 members through death, resignation and other causes. Despite the war conditions the membership continues to rise, and shows an increase of 27 over that of the previous year.

The list of deceased members is as follows :—D. F. Ashby, Professor H. L. Bowman, Mrs. A. J. Bull, W. G. Bullows, G. E. Dibley (*Hon. Mem*), A. Dovaston, H. H. Fawcett, W. H. Laurie, P. A. B. Martin, C. F. Pilcher, W. Platt, W. G. P. Thorold, L. Treacher and R. B. Yardley.

Obituary notices will be found on pages 38-44.

FINANCE

The Association is in a very sound financial position. The income from admission fees and annual subscriptions, at £481, was £33 10s. above the corresponding amount last year, and is the highest recorded since the outbreak of the War. The excess of income over expenditure for the year, as shown in the Income and Expenditure Account, amounts to £57 18s. 3d., bringing the accumulated funds up to £170 4s. 11d., and the balances in hand in the Special Funds have increased by £101 8s. 7d., and now amount to £242 11s. 8d. It should be noted, however, that the cost of the *Proccedings* does not include the cost of Part IV., the account for which was received too late for inclusion.

Bequest Funds.

A bequest of £100 from the late Dr. C. Davies Sherborn, was received during the year and was invested in 3% Savings Bonds 1960-70. A bequest of £300 from the late Mr. H. H. Fawcett has also been announced, but has not yet been received. It has been decided by the Council to amalgamate these bequests with the Morey and C. W. Andrews bequests into a single Bequest Fund. The Morey and C. W. Andrews Bequest Funds, therefore, disappear as separate Accounts.

Foulerton Award Fund.

One award of £10 was made during the year, the balance remaining in the Fund at the end of the year amounting to £12 1s. 8d.

G. W. Young, Geological Investigation Fund.

No grants were made from this Fund during the year. The balance in the Fund now amounts to £71, of which £20 is ear-marked in respect of a grant made to Mr. R. Casey in 1940. Mr. Casey's investigations have been interrupted by the War, but he hopes to resume them when more normal conditions return.

ACCOUNTS FOR THE YEAR ENDING DECEMBER 31ST, 1943.

GENERAL PURPOSES ACCOUNT

INCOME.

	£	s.	d.	£	s.	d.
To Admission Fees—						
Received for 1943 Elections	23	10	0			
Received for Arrears	2	0	0			
	25	10	0			
Less Arrears at December 31st, 1942, £4, estimated to realise	2	0	0			
	23	10	0			
Add Arrears at December 31st, 1943, £5, estimated to realise	2	0	0			
				25	10	0
To Annual Subscriptions :—						
(1) Received in 1939 and 1941 for 1943 ...	1	10	0			
(2) Received in 1942 for 1943	34	10	0			
(3) Received in 1943 for 1943	364	0	0			
(4) Received in 1943 for arrears	55	10	0			
	455	10	0			
Less Arrears at December 31st, 1942, £253 10s., estimated to realise	40	0	0			
	415	10	0			
Add Arrears at December 31st, 1943, £296 10s., estimated to realise	40	0	0			
				455	10	0
,, Sale of Publications				27	7	10
,, Miscellaneous Receipts					2	0
,, Transfer from other Accounts :						
From Illustrations Fund Account (for Illustrations)	40	0	0			
,, Reserve Fund for Index, etc. (for new List of Members.)	55	10	6			
				95	10	6
				£604	0	4

EXPENDITURE.

	£	s.	d.	£	s.	d.
By " Proceedings " of the Association (Vol. LIV, Parts 1-3)						
(1) Printing	168	8	6			
(2) Illustrations (a) Blocks and Plates	49	3	3			
(b) Printing	1	19	0			
(3) Authors' separate copies	13	17	6			
				233	8	3
,, Printing Monthly Circulars				28	3	0
,, Stationery				15	16	11
,, Expenses at Meetings				32	1	5
,, Addressing and Stock-keeping				37	17	11
,, Postages				88	0	8
,, Insurance				1	12	3
,, Incidental Expenses				3	11	2
,, Yearly transfer to Reserve Fund for Index and List of Members				50	0	0
,, Printing List of Members				55	10	6
,, Excess of Income over Expenditure				57	18	3
				£604	0	4

BALANCE SHEET, DECEMBER 31st, 1943.

LIABILITIES.

	£ s. d.	£ s. d.
To Annual Subscriptions received in advance :—		
In 1939 for 1944	10 0	
In 1942 for 1944	1 10 0	
In 1943 for 1944	52 0 0	
In 1943 for 1945	1 10 0	
In 1943 for 1946	1 10 0	
In 1943 for 1947	10 0	
		57 10 0
,, Cash received for Admission Fee and 1944 Subscription before election		1 0 0
,, Sundry Creditors :—		
Messrs. Benham & Co. Ltd.		3 10 0
Special Funds—		
Illustrations Fund	26 6 9	
Illustrations Fund (Capital)	20 0 0	
Reserve Fund for Index and List of Members...	18 0 0	
Compounding Fund	1,603 0 9	
Bequest Funds	549 10 9	2,216 18 3
		£2,278 18 3
Accumulated Funds at January 1st, 1943	112 6 8	
Add Excess of Income over Expenditure for the year ...	57 18 3	
		170 4 11
		£2,449 3 2

ASSETS.

	£ s. d.	£ s. d.
By Investments (Special Funds) at cost or value when acquired :—		
Bequest Funds—		
Morey Bequest.		
£100 0 0 3½% War Loan, at cost		100 0 0
C. W. Andrews Bequest		
£43 8 9 3½% War Loan at value when acquired	41 14 0	
£150 0 0 New Zealand 4½% Inscribed Stock 1944, at value when acquired	122 5 0	
£85 3% Defence Bonds, at cost	85 0 0	
		248 19 0
C. Davies Sherborn Bequest.		
£100 3% Savings Bonds 1960/70, at cost ...		100 0 0
Compounding Fund—		
£1,217 2 6 Nottingham Corporation 3% Irredeemable Stock, at cost ...	1,152 13 2	
£200 0 0 Savings Bonds 1955/65, at cost ...	200 0 0	
£170 0 0 3½% War Stock, at cost ...	152 14 5	
		1,505 7 7
,, Illustrations Fund (Capital) £21 0 10 Metropolitan Water Board 3% B Stock, at cost		20 0 0
,, Annual Subscriptions in Arrears, £296 10 0, estimated to realise		40 0 0
,, Admission Fees in Arrears, £5, estimated to realise		2 0 0
,, Cash at Bankers and in hand :—		
At Bankers	188 4 11	
In Office	2 0 0	
		190 4 11
,, Special Funds :—		
Illustrations Fund at Bankers	26 6 9	
Compounding Fund at Bankers	97 13 2	
Reserve Fund for Index and List of Members at Bankers	18 0 0	
Bequest Funds at Bankers	100 11 9	
		242 11 8
		£2,449 3 2

SPECIAL ACCOUNTS.

ILLUSTRATIONS FUND

	£ s. d.		£ s. d.
To Balance in hand on January 1st, 1943	7 16 3	By Transfer to General Purposes Account for Illustrations ...	40 0 0
,, Donations and Subscriptions	47 18 0	,, Balance December 31st, 1943, at Bankers	26 6 9
,, Contributions by Authors	10 0 0		
,, Transfer from Illustrations Fund (Capital)	12 6		
	£66 6 9		£66 6 9

ILLUSTRATIONS FUND (CAPITAL)

	£ s. d.		£ s. d.
To Balance in hand on January 1st, 1943	0 0 0	By Transfer to Illustrations Fund	12 6
,, Dividends as received :—		,, Balance December 31st, 1943	0 0 0
£21 0 10 Metropolitan Water Board 3% B Stock ...	12 6		
	£0 12 6		£0 12 6

COMPOUNDING FUND.

		£ s. d.		£ s. d.
To Balance in hand on January 1st, 1943		25 4 0	By Balance December 31st, 1943, at Bankers	97 13 2
,, Composition Fees received during the year ...		24 0 0		
,, Dividends as received :—				
£1,217 2 6 Nottingham Corporation 3% Stock	36 10 2			
£170 0 0 3½% War Stock	5 19 0			
£200 0 0 3% Savings Bonds	6 0 0			
		48 9 2		
		£97 13 2		£97 13 2

RESERVE FUND FOR INDEX AND LIST OF MEMBERS.

	£ s. d.		£ s. d.
To Balance in hand on January 1st, 1943	23 10 6	By Transfer to General Purposes of Account for List of Members ...	55 10 6
,, Yearly Reservation for 1943	50 0 0	,, Balance December 31st, 1943, at Bankers	18 0 0
	£73 10 6		£73 10 6

BEQUEST FUNDS.

	£ s. d.	£ s. d.		£ s. d.
To Balance, January 1st, 1943 (C. W. Andrews Bequest Fund)		51 2 4	By Purchase of £100 3% Savings Bonds, 1960/70 (Sherborn Bequest)	100 0 0
„ Balance, January 1st, 1943 (Morey Bequest Fund)		33 10 0	„ Balance December 31st, 1943, at Bankers	100 11 9
„ Legacy from Dr. C. Davies Sherborn		100 0 0		
„ Dividends as received :—				
£143 8 9 3½% War Stock	5 0 4			
£150 0 0 New Zealand 4½% Stock	6 15 0			
£85 0 0 3% Defence Bonds	2 11 0			
£100 0 0 3% Savings Bonds 1960/70	1 13 1			
		15 19 5		
		£200 11 9		£200 11 9

"TRUST" FUNDS.

FOULERTON AWARD FUND.

	£ s. d.		£ s. d.
To Balance in hand on January 1st, 1943	9 6 8	By Award to E. Montag, M.Sc., F.G.S.	10 0 0
„ Dividends as received		„ Balance 31st December, 1943, at Bankers	12 1 8
£255 0 0 Southern Railway 5% Guaranteed Preference Stock	6 7 6		
„ Income Tax repayment for 1942—1943	6 7 6		
	£22 1 8		£22 1 8

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND.

	£ s. d.		£ s. d.
To Balance in hand on January 1st, 1943	62 0 0	By Income Tax recovered for 1942, repaid to Public Trustee	10 0 0
„ Income for 1943 received from the Public Trustee	9 0 0	„ Balance 31st December, 1943, at Bankers	71 0 0
„ Income Tax repayment for 1942	10 0 0		
	£81 0 0		£81 0 0

We have compared these statements with the books and accounts presented to us and find them to agree.

We have also verified the investments of £1,217 2 6 Nottingham Corporation Stock, £200 Savings Bonds, 1955/65, and £170 3½% War Stock of the Compounding Fund, £255 Southern Railway 5% Guaranteed Preference Stock of the Foulerton Award Fund, £143 8 9 3½% War Stock, £150 New Zealand 4½% Inscribed Stock, £85 3% Defence Bonds and £100 3% Savings Bonds 1960 70 of the Bequest Funds, and £21 0 10 Metropolitan Water Board 3% B Stock of the Illustrations Fund (Capital).

E. C. MARTIN, *Treasurer.*
29th January, 1944.

A. D. STUBBS,
C. T. A. GASTER, } *Auditors.*

PUBLICATIONS.

Publications Committee. This Committee consisted of the officers (7), together with Mr. T. Eastwood, Dr. A. F. Hallimond, Dr. G. W. Himus, Dr. R. O. Jones, Dr. K. P. Oakley, Dr. R. W. Pocock, Dr. A. Wood, and Mr. A. Wrigley. The Committee met on three occasions, considered ten papers and made recommendations to the Council.

The Proceedings. The Regulations concerning the use of paper have restricted the size of the *Proceedings* as in 1942. The amount of geological work which is now being carried to completion is naturally limited, but the Committee has been able to secure sufficient suitable material to fill the available space.

Vol. LIV, published during 1943, consists of 193 pages, and was issued in the usual four parts. This volume contains six original papers, two presidential addresses, a report of the Annual Reunion, and the Annual Report of the Council for the preceding year. The papers are illustrated by 5 plates and 24 text figures.

Although it will not be possible to return to our normal type in 1944 an improvement in setting will, it is hoped, be found in our next Volume. The present 8-point type will be more freely leaded and we are arranging for casting 8-point on 9-point body. This should make for easier reading and reduce " dazzle," which has been commented on by members, a comment which the Editor entirely endorses.

MEETINGS.

Eleven meetings were held, at which three papers were read, five papers were read in extract, and six lectures were given. Particulars of these will be furnished later in the Session Report.

The thanks of the Association are due to the Authors and Lecturers. The attendance at meetings was well maintained, averaging 66.

The Ordinary and Annual General Meetings were held at the apartments of the Geological Society of London and the Committee meetings at the Imperial College of Science and Technology.

Tea was provided either before or after the Ordinary meetings.

The Association's thanks are due to the respective authorities for the generous facilities afforded.

REUNION.

The Annual Reunion was held at the Geological Survey and Museum on Saturday, 8th May. A number of interesting exhibits were shown and several short demonstrations were given by members. Thanks are due to the authorities, the organisers and the members concerned.

A full account of this meeting is given in the *Proceedings*, vol. liv, 1943, pp. 113-128.

FIELD MEETINGS.

The Secretary for Field Meetings, Miss E. White, resigned in November and Dr. G. W. Himus was appointed by Council to fulfil the duties.

It was not possible during the year to hold Field Meetings, but, in addition to the Annual Reunion (which is to replace the old " Conversazione ") at the Museum of the Geological Survey, afternoon visits were made to the Geological Department of the Imperial College and to the Natural History Museum. Reports of these meetings, which were well attended ,are given in the *Proceedings*.

The Council is anxious to make arrangements for the resumption of Field Meetings and visits at the earliest possible date. Members who are able and willing to act as Directors or Local Secretaries of meetings are therefore asked to communicate with the Secretary for Field Meetings.

The Field Meetings Committee is being reconstituted and it is hoped to arrange a skeleton programme which may be put into operation at short notice.

THE LIBRARY.

During the year the Library has been considerably augmented by a bequest from the late Mr. H. H. Fawcett, of Thorncombe (Dorset), consisting of about 60 general works on geology and related subjects, a number of Memoirs of the Geological Survey, and other literature. The Association is also indebted to Mrs. Scott-Smith for the gift of several books belonging to the late Mr. William Douglas, of Berkhamsted. Thanks are also due to the donors of several other books and pamphlets, a list of which will be given in the *Proceedings*.

Owing to its continued evacuation with the library of University College, the Association's Library has not been available for use by members during the year.

NORTH-EAST LANCASHIRE GROUP.

President of the Group : J. Ranson, A.M.I.M.E., F.G.S.

Joint Secretaries : A. Bray, M.Sc., A.Inst. M.M. (for correspondence) and Mrs. E. J. Harrop, B.A., B.Sc.

During the year three Lecture Meetings and four Field Meetings were held. A list of these will be published in the *Proceedings*.

On October 16th the Group celebrated its 21st Anniversary by a Field Meeting followed by tea. About 30 members attended.

The thanks of the Group are due to the Blackburn Education Committee for the continued use of rooms in the College.

MIDLAND GROUP.

President of the Group : Dr. F. Raw, D.Sc., F.G.S.

Secretary : Miss Grace M. Bauer.

Committee : Professor L. J. Wills, Miss Hignett, A. E. Lyon, Dr. C. E. Marshall, Dr. D. Parkinson and Miss M. E. Tomlinson.

During the year three Lecture Meetings and an Exhibition of Specimens were held at the Geological Department, the University, Birmingham, and two Field Meetings were held. Particulars will be published in the *Proceedings*. The attendance at the meetings was well maintained.

Thanks are due to Professor Wills for the use of the Geology Department at the University, Birmingham.

WEALD RESEARCH COMMITTEE.

Chairman's Report for 1943. While no systematic field work is yet possible, a paper was given by Mr. G. S. Sweeting which arose from his past work in the Weald. It was entitled " Wealden Iron Ore and the History of its Industry," and it is intended to publish it as a Committee Report.

TRUSTEES.

The following are the Trustees of the Association :—

Managing : Mr. F. N. Ashcroft, M.A., F.G.S., F.C.S., F.R.G.S., Mr. S. Hazzeldine Warren, F.G.S., and Sir Arthur Smith Woodward, LL.D., F.R.S., F.G.S.

Custodian : The Royal Bank of Scotland, Western Branch.

FOULERTON AWARD.

The Foulerton Award for the year was given to E. Montag, M.Sc., F.G.S., in recognition of services rendered to the Association.

HOUSE LIST.

Professor H. H. Read retires as President after two years' assiduous guidance of the affairs of the Association. Professor W. B. R. King and Professor H. L. Hawkins also retire as Vice-Presidents. Miss E. White has resigned from the office of Secretary for Field Meetings which she has filled since 1937, and her efficient arrangements have contributed much to the success of the Field Meetings held prior to the outbreak of war. Dr. R. W. Pocock and Messrs. E. E. S. Brown and G. W. Pirie retire as Ordinary members of the Council. Thanks are due to these members for services rendered to the Association.

REPORT OF THE SESSION, 1943.

ORDINARY MEETING, *January 9th*, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

William Finlay Bennett, Archibald Cecil Dalton, Henry Alfred Page Hetherington, Stanley Lionel Lightfoot and Ernest Wright, B.Sc., were elected members of the Association.

Messrs. F. W. H. Migeod and A. T. Stubbs were elected to audit the accounts for 1942.

The following lecture was delivered :—" Fullers Earth," by R. H. S. Robertson, M.A.

ORDINARY MEETING, *February 6th*, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

Miss Elsie Mabel Pracy, B.Sc., and Sergius Theokritoff were elected members of the Association.

The following lecture was delivered :—" The Determination of Minerals by X-Ray Methods," by F. A. Bannister, M.A.

ANNUAL GENERAL MEETING, *March 6th*, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

The Annual Report of the Council (already circulated) was taken as read. It was moved by Mr. F. N. Gossling and seconded by Mr. D. Bromehead, " that the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for 1942." The resolution was carried *nem. con.*

The President declared the following members duly elected as Officers and Members of Council in accordance with Rule XIII :—*President*, Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S. *Vice-Presidents*, Professor W. B. R. King, O.B.E., M.A., F.G.S., Professor H. L. Hawkins, D.Sc., F.R.S., F.G.S., Miss Emily Dix, D.Sc., F.G.S., W. P. D. Stebbing, F.S.A., F.G.S., L.R.I.B.A., C. E. N. Bromehead, B.A., F.G.S. *Treasurer*, E. C. Martin, B.Sc., A.I.C., F.G.S.

Secretaries : General, A. G. Bell, I.S.O., B.Sc., F.G.S. *Field Meetings*, Miss E. White, B.Sc., F.R.G.S., F.G.S. *Publications Committee*, A. J. Bull, Ph.D., M.Sc., F.G.S. *Editor*, G. S. Sweeting, D.I.C., F.G.S. *Librarian*, L. R. Cox, M.A., Sc.D., F.G.S. *Twelve other Members of the Council*, E. E. S. Brown, M.B.E., F.G.S., T. Eastwood, A.R.C.S., F.G.S., A. F. Hallimond, M.A., Sc.D., F.G.S., G. W. Himus, Ph.D., M.I.Chem.E., R. O. Jones, Ph.D., M.Sc., F.G.S., Miss H. M. Muir-Wood, D.Sc., F.G.S., M. A. Ockenden, F.G.S., M.I.Mech.E. G. W. Pirie, F.G.S., R. W. Pocock, D.Sc., F.G.S., H. E. Taylor, F.G.S., Alan Wood, B.Sc., Ph.D., F.G.S., A. Wrigley.

It was moved by Dr. R. L. Sherlock, seconded by Mr. Withers, and duly carried, " that the best thanks of the Association be given to the Officers, the retiring members of Council and the Auditors."

The Foulerton Award was presented to Mr. E. Montag, M.Sc., F.G.S., in recognition of services rendered to the Association.

The President said :—

Mr. Montag : An ambassador has been defined as a man who lies abroad for his country's good and I suppose the same definition applies to consuls. For some 50 years now you have lain abroad. Whatever may be the opinion of your country as to the good it has derived by this, we are certain here that it has been to ours, for from your personality, energy and enthusiasm, generations of geologists have received lasting benefits. You have acted as Excursion Secretary for the Association on six occasions, you have contributed to the knowledge of the geology of our country by your publications, and you have made available to us in your admirable translations the classics of your Swiss master, Heim. On all these counts and others you have deserved well of geologists and, in handing you the Foulerton Award, I express the appreciation and gratitude of this Association. I desire to add my personal thanks for your many kindnesses when I found myself unexpectedly translated to the Liverpool district.

Mr. A. L. Leach, F.G.S., was elected an Honorary Member of the Association.

The President then delivered his Address, entitled " Meditations on Granite ; Part One."

On the motion of Mr. W. H. Steele, seconded by Mr. A. T. Marston, it was resolved " That the President's Address be printed and circulated among the members."

ORDINARY MEETING, *March 6th*, 1936.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

The Rev. Charles Hamilton Arnold, M.A., Frederick Ashby, John Alexander Dell, Victor Charles Robert Ford and Frederick William Prime were elected members of the Association.

ORDINARY MEETING, *April 2nd*, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

The following paper was read :—" The Pleistocene Rocks of Trebetherick Point, North Cornwall : Their Interpretation and Correlation," by W. J. Arkell, M.A., D.Sc., F.G.S.

ORDINARY MEETING, *May* 7th, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

John Frederick Brown, William Cecil Gregory, Gunter Nagelschmidt, D.Phil., and Alan William Reece were elected members of the Association.

The following paper was read :—" The Compression of a Sheet (A Study in Tectonics) " by A. J. Bull, Ph.D., F.G.S.

ORDINARY MEETING, *June 4th*, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

Maurice Hubert Stucley Barker, B.Sc., F.G.S., A.A.P.G., Harry Coy, and Peter Edwin Negus were elected members of the Association.

The following lecture was delivered :—" Coal in North America," by C. E. Marshall, B.Sc., Ph.D., F.G.S.

ORDINARY MEETING, *July 2nd*, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

Mrs. Glenys Howell Barker, Edwin James Hesketh, Donald James Jenkins, Mrs. Nellie Maylott, Andrew Ford Seager, and N. W. Simmonds were elected members of the Association.

The following lecture was delivered :—" The Yellowstone National Park, U.S.A.," by Professor O. T. Jones, M.A., D.Sc., F.R.S., F.G.S.

ORDINARY MEETING, *October 2nd*, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

Gordon Frederick Andrews, Miss Sylvia Davis, Miss P. M. Kirkland, Mrs. Joyce Newport, and Miss Cicely Mary Willis were elected members of the Association.

The following paper was read :—" Wealden Iron Ore and the History of its Industry," by G. S. Sweeting, D.I.C., F.G.S.

The following paper was read in abstract :—" The Salopian Rocks and Geological Structure of the Country around Eglwys-Fâch and Glan Conway, N.W. Denbighshire." by Professor P. G. H. Boswell, O.B.E., D.Sc., F.R.S., F.G.S.

ORDINARY MEETING, *November 6th*, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

Henry Charles Cunningham, Rhys Glyn Davies, Harold Elliott, Robert Blackadder Fisher, Cyril Edward Higgs, B.Sc., A.R.C.S., James Jack, Kerry Bernard Jones, Ivan Kostov, Igor Serge Loupekine, Derek Michael Phillips Phillips, Robert Hilditch Price, Cecil Frederick Sayers, Bertie Speight, Frank Clifford Stallybrass and Rupert Cavendish Skyring Walters, B.Sc., M.Inst.C.E., F.G.S., were elected members of the Association.

The following lecture was delivered :—" Glacial and Post-Glacial Sediments in the Windermere Basin," by Mrs. T. G. Tutin (Miss W. Pennington).

The following papers were read in abstract :—(1) " Some Aspects of Percolation in S.E. England," by W. V. Lewis, M.A. ; (2) " A New Section in the Lower London Tertiaries near West Wickham, Kent," by G. W. Himus, Ph.D., F.G.S., and Alan Wood, Ph.D., F.G.S.

ORDINARY MEETING, *December 4th*, 1943.—Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S., President, in the chair.

Gerhard Horst Alt, John Arrowsmith Best, Paul Desmond Blake, Miss Mollie Millicent Brown, Miss Monica Mary Cole, James Davies Hughes, Harold Leslie Nixon, B.A., Leslie John Pitt, James Robertson and Miss Mary Sharp were elected members of the Association.

The following papers were read :—(1) " Basic English and Its Use in Geology " ; *(2) Organs of Reproduction in the *Solenoporaceae*." [**Read in Abstract only*.] Both Papers by Alan Wood, Ph.D., F.G.S.

NORTH-EAST LANCASHIRE GROUP.

The following Meetings and Field Meetings were held during the year 1943 :—

February 15th.—Lecture, " The Geology of Cement," J. Olney, B.Sc.

March 19th.—Presidential Address, " The Geology of the Isle of Man," J. Ranson, F.G.S.

April 7th.—Field Meeting. The Darwen District. *Leader :* E. J. Harrop, B.Sc., B.A.

May 29th.—Field Meeting. Whalley Gap. *Leader :* J. Ranson, F.G.S., A.M.I.M.E.

June 26th.—Field Meeting. Salewheel and Ribchester. *Leader :* J. Ranson, F.G.S., A.M.I.M.E.

October 16th.—21st Anniversary Celebration. Field Meeting to Darwen Moors. *Leader :* Mrs. E. J. Harrop, B.A., B.Sc.

November 21st.—Lecture, " The Natural History of the Chemical Elements," J. Scott, B.Sc.

MIDLAND GROUP.

The following Meetings and Field Meetings were held during 1943 :—

March 13th.—Lecture, " A Geologist in Orkney," by Lt. A. Ludford.

May 15th.—Lecture, " Refractory Minerals in Geological Perspective," by Dr. W. O. Williamson.

June 19th.—Field Meeting to Barrow Hill near Dudley. *Leader :* Dr. C. E. Marshall. A party of fifteen, under the direction of Dr. C. E. Marshall, spent the afternoon of Saturday, June 19th, in examining the field relations of the Barrow Hill " basalt." Particular attention was paid to the evidence of fault movements and their control of and effect upon the intrusions. The unusual nature of the country rock was examined as well as the more interesting macroscopic characters of the igneous rocks.

August 21st.—Field Meeting to Romsley. *Leader :* Professor L. J. Wills. Starting at the top of Romsley Hill, a party of twelve followed a route chosen to demonstrate the relation of the detailed topography to the geological structure. After tea at the house of the director, the party returned via Rubery in order to examine a large new exposure in Glacial sand and gravel, the horizontal bedding of which suggested that deposition took place in a lake. This could only have come into existence at the edge of a large mass of ice filling up the lower ground of the Severn valley. A new exposure in the Clent Breccia was also examined.

October 16th.—Exhibition of Specimens. Professor Wills and Dr. Marshall showed colour photographs of Llangollen, Hope and Barrow Hill districts. Mr. J. A. Best described his own method of model making, models of Ben Nevis, Glen Roy and Habberley Valley being on view. Dr. F. Raw, showed rocks from Merioneth and Mr. J. D. Hughes fossils from Craven Arms area.

November 13th.—Lecture, "Earthquakes and Geology, Part I," by Dr. F. Raw.

December 11th.—Lecture, "Earthquakes and Geology, Part II," by Dr. F. Raw.

DONATIONS TO THE LIBRARY DURING THE YEAR 1943.

DALTON, A. C. Lake Humber as Interpreted by the Glaciation of England and Wales. 1943.

GEOLOGICAL SURVEY. Geology of the Forest of Dean Coal and Iron-Ore Field. 1942.

MALVERN FIELD CLUB. The Geology of Malvernia. By A. Bennett. 1942.

MOORE, L. R. and A. H. COX. The Coal Measure Sequence in the Taff Valley, Glamorgan, and its Correlation with the Rhondda Valley Sequence. 1943.

NEIVA, J. M. COTELO. Six pamphlets on the petrology of Portugal. 1941-3.

PLATTEN, G. The British Caver, vols. 10 and 11. 1943.

STEBBING, W. P. D. Stonar and the Wantsum Channel. Part III.—The Site of the Town of Stonar. By the donor and the late F. W. Hardman. 1943,

TREACHER, Mrs. Ll. An Attempt towards a Natural History of the Fossils of England ; in a Catalogue of the English Fossils in the Collection of J. Woodward, M.D. By J. Woodward. 2 vols., 1728-9.

OBITUARY NOTICES.

Donald Frederick Ashby, who lost his life so tragically in the Barmouth Estuary, was in his twenty-ninth year, and was educated first at the Sloane School, Chelsea, and later at the Imperial College of Science and Technology. After graduation he proceeded to the study of the Lower Carboniferous sediments and interbedded volcanic rocks of the Old Pallas district in Co. Limerick. A summer field meeting in Ireland had been planned for 1939 and Ashby contributed a preliminary account of the area to which he had devoted so much time in the previous four years (*Proc. Geol. Assoc., vol.* 1, 1939) ; although the meeting was not held owing to the outbreak of war, it was fortunate his paper was printed, otherwise there would have been no published record of the results he had won from the Limerick area.

In 1938 Ashby was chosen as geologist to the first Arctic Expedition of the University of London of which Jan Mayen Island in the Greenland Sea was the objective, and his geological investigations there were concentrated in the mid-region of the Island. His skill as a mountaineer was evident from the successful ascent of the Beerenberg which he made with other members of the expedition. Ashby's promise as a geologist was recognised by his appointment to the staff of the University of Bristol and later by the Geological Society of London in the award in 1941 of the Daniel Pidgeon Fund ; he had been a member of the Association since 1934. His bright, happy and enthusiastic companionship won Ashby many friends, who will also remember how he enlivened many an evening by his able performances as a pianist.

[W.F.W.]

Hugh John Llewellyn Beadnell. A large circle of friends and fellow-workers will have heard with deep regret of the death of Major H. J. L. Beadnell, whose name will always be associated with one of the most important advances made in our knowledge of the vertebrate life in Egypt during the Oligocene and Eocene periods.

He was born on the 14th October, 1874, and was the second son of the late Major C. E. Beadnell, R.A., J.P., Montgomeryshire, and Mrs. Beadnell, daughter of George Bailey, Esq., of Gloucester. Beadnell received his education at Cheltenham College, King's College, London, and the Royal College of Science, where he studied Geology under Prof. J. W. Judd. The present writer (then acting as Senior Demonstrator in the geological department at the Royal College of Science) first met him at this time and was much impressed by his enthusiasm and energy.

When Sir Henry Lyons applied to Prof. Judd for helpers to work under him on the newly founded Geological Survey of Egypt in 1896, the late T. Barron and Beadnell were selected, Beadnell being associated with the work of the Survey from 1896 to 1906. During this period he carried out geological studies in Dakhla, Farafra and Baharia Oases, but his two major memoirs, which have since become classical for the areas surveyed, were those on the Cretaceous region of Abu Roash, near the Pyramids of Giza, and on the Topography and Geology of the Fayum. In 1901 Dr. C. W. Andrews had been granted special leave by the Natural History Museum authorities for convalescence after illness to come to Egypt. Beadnell and the present writer were then sharing a home in Helwan, near Cairo, and invited him to be their guest. In April of that year Beadnell invited Andrews to accompany him on one of his expeditions to the Fayum and during it, remains were obtained of the Middle Eocene elephant *Moeritherium*, also the sirenian *Eosiren* and the snake *Gigantophis*, etc. A second expedition, together resulted in the finding of the first traces of *Palaeomastodon*. Subsequently Beadnell carried out further researches in the Fluvio-marine Beds (now mainly considered to be Oligocene), during which he discovered the great fossil mammal *Arsinoitherium* of which he gave a brief description, giving it the specific name of *Zitteli*, to honour the great palaeontologist, whose work in the Oases he was so well able to appreciate.

In 1905 Beadnell studied the relations of the Eocene and Cretaceous Systems in the southern Egyptian reach of the Nile between Esna and Aswan. In 1906 he became manager of a company developing an area in Kharga Oasis. During 1906-1910 he was responsible for the reclaiming of extensive tracts of desert in this oasis depression by the sinking of artesian bores. The results were recorded in his interesting volume, " An Egyptian Oasis," 1909.

In 1904 Beadnell married May Grace Thompson, niece of Mr. Quibell (Curator of the Museum of Antiquities, Cairo) and Mrs. Quibell and granddaughter of the Very Rev. W. R. Pirie, D.D., Principal of Aberdeen University. She pre-deceased him in 1942.

From 1912 to 1915 Beadnell was ranching in British Columbia. He enlisted in the Artists Rifles 1916, and served with the Egypt Expeditionary Force 1916-1919 as recruiting officer, obtaining the rank of Major and Acting Lieut.-Colonel on demobilisation. He then surveyed Central Sinai for the Whitehall Petroleum Company of which the general account appeared in his " Wilderness of Sinai," 1927. Rejoining the Egyptian Government service in the Petroleum Research branch of the Geological Survey he surveyed the western coasts of the Red Sea. His report on this area appeared in 1924. He then transferred his activities to the mapping and sinking of two deep wells, Bir Sahra and Bir Messalia, on the hitherto waterless desert route in the south-west Libyan Desert between the Darb el Arbain (south of Kharga Oasis) and Owenat Oasis 1927-1929. This effort was undertaken on the basis of the late Dr. Ball's views as to the distribution of underground water in this region, and water was obtained close to the limits in depth indicated by him. Unfortunately Beadnell here laid the foundation of the silicosis which was to be his trial in later years. He then became Resident Engineer on the Qattara Depression hydro-electric project of the Egyptian Government, 1930-1932. Since then he had been living in London, and specially interested himself in gemmology.

In 1904 he received the Barlow-Jameson Fund from the Council of the Geological Society, and also recognition from the Royal Geographical Society for his work in the Egyptian Deserts. His Esna-Aswan paper was contributed to the *Quarterly Journal Geological Society*, 1905, while for the *Geographical Journal* he wrote important papers on the Libyan Desert Sand Dunes and on Central Sinai.

When war broke out with Germany in 1939, Major Beadnell again took up military duties, acting as a recruiting officer. He died on January 2nd, 1944.

He is survived by his elder brother, Surgeon Rear-Admiral C. M. Beadnell, who has had a distinguished naval and literary career, and by a daughter, who is the assistant County Medical Officer of Health for Hertfordshire.

In his spare moments Beadnell was a keen sportsman, and in the winter months the writer accompanied him on duck and grouse-shooting expeditions in the marshy country on the borders of the Nile and the desert. He marked his arrival in Egypt by successfully undertaking the hazardous ascent of the Second Pyramid, which must have required agility and climbing craft of no mean order. He devoted himself without stint to the work he had in hand, and was loyal alike to his family, his friends and his country. As one of the trio of the three B's (Barron, Ball and himself) who were pioneers of the Geological Survey of Egypt, his memory will always remain highly esteemed in Egypt and by his companions he will always be held in grateful remembrance.

[W. F. H.]

Professor Herbert Lister Bowman, who died on 22nd April, 1942, at the age of 68, joined the Association as a Life Member in 1900. Educated at Eton

College and New College, Oxford, where he studied chemistry and physics, he took his M.A. degree in 1895, and the D.Sc. in 1908. In 1898 he studied mineralogy for eight months under Prof. Groth at Munich and on returning to Oxford, where he had previously helped in the arrangement of the mineral collection in the Museum, he was appointed demonstrator in mineralogy. He became Waynflete Professor of mineralogy in 1909, in succession to Professor Miers. Most of his papers dealing with the properties and modes of occurrence of minerals are published in the *Mineralogical Magazine*. At different times he served as Recorder of the Geological Section of the British Association, Secretary to the Delegates of the University Museum, Oxford, and Vice-president of Magdalen College and of the Mineralogical Society.

WILFRED LAWSON BULLOWS, who died on July 20th, 1943, in his 74th year, took up geology late in life. He was a hardware manufacturer of Walsall, Staffs., the business having been established by his father Alfred Bullows, whose name it still bears. He was a member of the Birmingham Archaeological Society, to whose Transactions he contributed three papers, and so also of the Birmingham Natural History and Philosophical Society, of whose Geological Section he was for a time President ; he joined the Geologists' Association in 1937.

It seems to have been archaeological interest and excavation that turned his attention towards geology. In the sessions 1929-30 and 1930-31 he attended classes in geology at the Midland Institute in Birmingham. Having been thrilled by a geological excursion to the glacial overflow channel, waterfall and gorge of Habberley Valley near Kidderminster, he commenced to study the evidences of drainage changes in his home district of the North Midlands and to interpret them largely in terms of the local glaciation. To this study also he devoted his holidays in North Wales, which he had already extensively traversed, and in Scotland, especially the regions of Lochaber and the Great Glen. In this he was highly successful, and his work displays keen observation and keen but well controlled imagination. He was not, however, equally happy in expressing himself, and did not achieve publication. His observations and conclusions are represented by his typed notes illustrated by numerous beautifully drawn maps and sections, which he deposited in the Birmingham University Library. The work which he did in the last twelve years of his life, greatly handicapped as he was by ill health, is evidence of the quality of his mind : at the same time he endeared himself to a wide circle of friends.

[F. R.]

WILLIAM DOUGLAS, who died on 29th October, 1943, was born at Crosshouse, Ayrshire in 1865. At the age of 19 he went to British Guiana as an analytical chemist on a sugar estate. He rapidly became one of the best known authorities on sugar and travelled all over the world. In 1910 he returned to this country where he was actively connected with various sugar growing companies until a few years ago. His interest in geology started in his youth and continued throughout his life, many excursions and holidays being spent with his hammer, collecting specimens to be studied at leisure. He joined the Association in 1923.

[M. E. S. S.]

ADOLPHUS DOVASTON, who died at his home at Ealing on 15th May, 1943, at the age of 84, had been a Life Member of the Association since 1886. Educated at Shrewsbury School, he became an architect by profession and obtained appointments under the Metropolitan Board of Works, and later the London County Council, with which body he remained, as head of the Dangerous Structure Section, until his retirement in 1922. He designed the buildings for the first exhibition at Earls Court, the American Exhibition. One of the founders of the Ealing Arts Club, he served for many years as its chairman, and since 1935 as its president. He was an enthusiastic Freemason and held a distinguished position in the craft.

Henry Hargreaves Fawcett, who died on 5th May 1943, at the age of 62, joined the Association in 1907 and was a Life Member. Educated at Westminster School and Worcester College, Oxford, he entered London University as a medical student, but abandoned a medical career as the result of ill-health and lived for 32 years at the village of Thorncombe in Dorset, where he took a prominent part in many local activities. He was an enthusiastic student and amassed a considerable library. After leaving London he became an extra-mural member of Edinburgh University. For the last three years of his life he endured a long and painful illness with patience and fortitude.

William Henry Laurie, who, after a long nervous breakdown, died on 20th February, 1943, at the age of 59, came of a Scottish stock, several members of which have attained eminence. Born at Penicuik at the northern foot of the Pentland Hills, he started work early in a paper mill and rose to a position of trust. But he had wide scientific interests with astronomy and geology as his special hobbies, interests that were fostered by membership of the Heriot Watt College, the local Natural History Society and of the Geological Society of Edinburgh. With these he studied the geology of his district, and made himself a very competent field geologist. He maintained also throughout life his interest in astronomy and was expert in computing sundials, the detailed angles for which he often furnished. The Great War made him a draughtsman in the Army Service Corps. and he was later in the Army of Occupation on the Rhine.

In 1920, under Professor W. S. Boulton, he was appointed assistant in the Geological Department of Birmingham University and later Curator in its Geological Museum. Here he joined the Birmingham Natural History and Philosophical Society, and the Geologists' Association in 1935. Becoming keenly interested in Midland geology he was constantly among the first to inspect and record any new local exposures, and with Professor Boulton he was associated in several pieces of research. Being also an excellent draughtsman he drew the illustrations to many scientific papers.

His death is a loss to Midland geology, and his wide scientific knowledge, his craftsmanship and his readiness to help are missed by a wide circle.

[F. R.]

Percival Alfred Buxton Martin, who died on 9th October, 1943, aged 86 years, joined the Association in 1897 and was a Life Member. He was born at Bank House, Chipstead, Sevenoaks, and lived there until his death. A builders' merchant by profession and a pioneer of early motoring, he was a man of wide and varied interests, a member of the Kent Archaeological Society and a keen botanist and gardener. His collection of flint implements has been deposited in the Museum at Sevenoaks. In his younger days, about 1910, he actively served the Association by conducting several Field Meetings in the Sevenoaks district.

William Platt, who died at Stanmore, Middlesex, after a short illness on 25th March, 1943, at the age of 76, joined the Association in 1920 and became well known as a regular attendant at both Ordinary and Field Meetings. Leaving school at the age of 16 he at first entered business, but his temperament inclined him more to literature and music and his early poems and novels secured for him a place in literary and artistic circles in London. He married in 1897 Miss Susan Willis, and in 1908, with Mrs. Platt, founded a co-educational boarding school amidst the lovely scenery of North Derbyshire. This venture was a success and continued until 1920, when he returned to London and thereafter devoted his energies mainly to writing and lecturing. He had a graphic style and a lively sense of humour, which enabled him to hold the attention of audiences of all ages. With children and young people he was particularly successful. A few weeks before his death he was lecturing to members of the Forces. It was amongst the hills and moors of Derbyshire that he began to find an absorbing study in geology ; a paper in the *Proceedings* records some of his work there. By his many friends in the Association he will long be remembered for his engaging personality and unfailing good humour.

CHARLES F. PILCHER, who died suddenly on 7th December, 1943, at the age of 64, was the son of the late Charles Robert Pilcher and was born at Old Ford, Bow. Educated at King's College and trained as a schoolmaster, he held several appointments at schools in London. He joined the Association in 1922 and served on the Council from 1933 to 1937. A man of wide and varied interests, he was a member of the Quekett Microscopical Club, the Essex Field Club and a Fellow of the Geological Society. Upon his retirement to Bournemouth in 1939, his large collection of geological specimens was deposited in a school museum.

WILLIAM GEORGE PRESTON THOROLD, B.A., Deputy Chief Engineer of the Metropolitan Water Board, died suddenly of heart failure on April 23rd, 1943, aged 51 years. Educated at Winchester College he went up to New College, Oxford, and obtained his B.A. degree in 1914. During the 1914-18 war he eventually commanded the Signal Section of the 4th Cyclists Brigade. After the war he joined the Metropolitan Water Board, and in 1932 was made Western District Engineer. In 1937 he was appointed Distribution Engineer to the Board and later Deputy Chief Engineer. Thorold was elected an Associate Member of the Institution of Civil Engineers in 1928 and became a Member in 1937. He was also an Associate Member of the Institution of Mechanical Engineers and a Member of the Institution of Water Engineers. He was an extremely active man, a keen observer and a good field geologist, most of his geological work being confined to water problems. He made his own rock-sections of the bores, etc., and did much petrological work.

[E. P. B.]

LLEWELLYN TREACHER. By the death, on 14th February, 1943, of Llewellyn Treacher, the Geologists' Association lost one of its oldest and most honoured members. Born at Twyford in 1859, Treacher was a descendant of a family that were distinguished for their constructive engineering work, especially in the building of the bridges and locks of the Upper Thames. After receiving his education at boarding schools in Reading and Maidenhead, Treacher, at the early age of 16 years, joined his father in business as a market gardener and fruit grower, and his wide knowledge of soils and drainage was thus gained. As a result of annual family visits to the Isle of Wight his attention was attracted towards geology, and Mantell's classic work on the geology of that island was the first book he possessed on his favourite subject. He soon widened his studies by the examination of the Cretaceous and the Pleistocene rocks of his own neighbourhood, and in scarcely any other district could such studies be followed with better chances of success. Later he collaborated with Mr. Osborne White with important results, the most valuable contributions being their researches on the phosphatic chalk and especially its faunal and zonal characteristics, of Taplow and other places in the western end of the London Basin.

Another subject of great interest that engaged his attention, and one of economic importance with regard to the search for artesian water, was the extent of the transgression of the Tertiary beds across the zones of the Upper Chalk and the amount of pre-Tertiary erosion of the Chalk indicated by this transgression. For this work the Geological Society of London in 1913 awarded him the Lyell Fund.

For many years the beautiful fossils of the Faringdon Gravels proved a great attraction, and during his many visits he amassed not only his large collection of specimens, but also acquired his unrivalled knowledge of these gravels. Among the forms he collected was an echinoid which Professor Hawkins described as *Cidaris coxwellensis*, and as the only complete Cidaris ever found there.

The abundance of Polyzoa in the beds led him to their detailed study and to extend his search for them in the Chalk, but as he wrote very little about his fine collection it is satisfactory to know that it has been acquired by Reading University and thus made available for further research. His interest in palaeolithic implements was initiated by an amateur of great enthusiasm, a Dr. Stevens, of Reading, who urged him to search for implements in the gravels around Twyford. This he did, and in a few days found his first specimen in the gravel of his own orchard. Treacher soon became an authority on the subject of the terraces of the Thames between Reading and Slough, and his ardour in following up every line of evidence helped him to bear the inevitable disappointments arising from gaps in such evidence. Not a single gravel pit, of which there were over 50, escaped his attention, while in order to train the gravel diggers he carried with him examples of implements which he showed to the men, and he stressed the necessity of recording the exact provenance of each find. In this way his wonderful collection grew and its value became proportionate to the accuracy of such location. He was, however, no mere curio collector, for he early formed the opinion that palaeoliths could be used as " zone fossils " and his later years he devoted much thought to testing their value for this purpose. In this important work he was much assisted by his wife, formerly Miss Mabel Elliott, daughter of Dr. Elliot of Oundle, and it is fortunate that their researches have been, in part, recorded by her. It is to be hoped that some at least of the great store of his observations and conclusions may be published.

He attained to such knowledge of the different forms of palaeoliths and of the style of their manufacture that he was able correctly to assign to their respective sources almost any implement shown him. But he doubted the validity of the numerous substages ascribed by some recent collectors to the Acheulian and the Mousterian industries. Incidentally, he found in the gravel at Furze Platt, Maidenhead, the largest implement ever found in this country and presented it to the Natural History Museum, South Kensington. Casts of it have been sent to museums in many parts of the world.

The point he always stressed was the help afforded by palaeoliths in distinguishing the deposits of the several terraces of the Thames and its tributaries from one another, and so determining the history of their development.

Treacher conducted some 25 excursions of the Geologists' Association : his work was much appreciated by them as was shown by the award to him in 1921 of the Foulerton Fund.

By nature he was cautious and therefore disinclined to carry hypothesis farther than the evidences warranted, but he unfortunately suffered from the defects of his virtues, and as a result became reluctant to publish at all. It is to be deeply regretted that so much knowledge should have thus been lost to science.

Treacher was richly endowed with qualities that endeared him to all who knew him ; his originality and independence of thought struck those also who did not share his scientific interests. He was generous, kind and helpful to those who sought his advice and was moreover a charming companion in the field. The writer looks back with feelings of pleasure to the many delightful days spent in the field with him and is grateful for much information given in a characteristic unobtrusive way.

Treacher died at Twyford, where he had lived most of his life, and it seems fitting that in Ruscombe churchyard he rests among the deposits that had so deeply interested him.

[H. D.]

Robert Blake Yardley, M.A., who died at Witham, Essex, on 25th January, 1943, at the age of 84, joined the Association in 1886. The only child of the late Charles Yardley, he was educated at King's College School, London, and King's College, Cambridge, taking the Mathematical Tripos in 1881. He was called to the Bar at the Inner Temple in 1882 and practised at Lincoln's Inn from 1884. In 1929 he was appointed Justice of the Peace. A world-wide traveller and a man of varied interests, Yardley willingly gave his services to many public and other bodies such as the Surrey County Council and other local authorities. He served on the Council of the Land Union from its foundation and was for fourteen years its honorary secretary. He was a Governor of the Foundling Hospital for twenty years. A distinguished philatelist, he was President of the Royal Philatelic Society from 1931 to 1934. In addition to geology, botany and music also claimed his interest. He married, in 1895, the daughter of the late Major-General W. H. Binny. He was a director of the Yardley Perfumery Company.

MEDITATIONS ON GRANITE : PART TWO.

By Professor H. H. READ, D.Sc., F.R.S.

(Presidential Address delivered March 4th, 1944.)

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I. CONNECTIVE.

IN Part One (*Proc. Geol. Assoc.*, vol. liv, 1943, pp. 64-85) of these meditations presented to you a year ago, I essayed among many other aims to arrive at acceptable statements concerning a number of aspects of the common everyday geological adjective igneous. I trust that you agreed with me, in the first place, that the igneous rocks are those, and only those, that have consolidated from a molten fluid, in the second place that this molten fluid or magma may have been produced in a variety of ways, and lastly that its ancestry does not affect in any way the legitimacy of its products—they are all igneous rocks. We agreed, I continue to trust, that weighty and cosmopolitan authority had pronounced granite to be an igneous rock and accordingly I passed in review the proposals dealing with the origin of granitic magma. We saw that formidable objections had been raised against the derivation of granitic magma through the crystal-fractionation of a primary magma of basaltic composition ; we preferred, again I venture to hope, to consider that granitic magma was primary in its own right, and we noted the possibility that the sialic layer of the crust might be its source. Finally, after many buffetings, we fetched up for the year in the haven of the great thought that possibly the igneous rocks might be of two fundamentally different qualities—the volcanic and the plutonic associations. Refitted and refreshed, we now push out on a new Odyssey.

What lies before us today is this. We have first of all to consider at some length the proposals concerning granitisation, that is, broadly speaking, the acquisition of granitic characters by rocks of one kind or another. The validity and scope of granitisation processes are questions which now divide petrologists more sharply than any others. This same division has lasted for nearly a century ; its causes and results are worth examining. We shall find—and I hope find reasonably—that there is an excellent case to be made out for granitisation.

Once this has been admitted, we shall realise that rocks with granitic characters have been formed in more than one way—there are granites and granites ; some granitic rocks are of igneous origin, others arise by granitisation. We have to examine, however, the possibility of all kinds of granitic rocks, igneous or not, being the consequence of one cause and marking stages in one unified process. We then seek to extend this unification still farther so as to embrace the metamorphic rocks and thus to interpret the whole of the classic group of the Primary Rocks as results of one mechanism. During these deliberations, that ancient and respected term igneous will be found to have become shorn of its importance. But once we have the true measure of the igneous idea, once we realise the amount of extra-belief which has accumulated around its primitive kernel of utility, we shall be prepared for a reorientation of our views on rocks—a reorientation which is simply nothing more, and nothing less , than a return to Lyell.

II. GRANITISATION: DEFINITIONS.

It will be as well to preface the consideration of granitisation with an examination of the significance of the term. There is no need here to trace its history and I content myself with a few recent statements from selected diverse sources.

My first definition and discussion come from one of the most important of the modern papers on granitisation, that on the Inyo Range by G. H. Anderson (" Granitization, Albitization and Related Phenomena in the Northern Inyo Range of California-Nevada," *Bull. Geol. Soc. Amer.*, vol. 48, 1937, pp. 47, 49) ; Anderson states :

" Granitization has never been precisely defined. In a narrow sense it should relate to the formation of a granite, but, as, theoretically, rocks formed by replacement and recrystallisation may have the composition of monzonites, granodiorites, diorites or gabbros, the term might well be extended to these. This would avoid such cumbersome terms as ' granodioritization ' or ' gabbroization.'

" Used in this sense, granitization is a complex process, involving both recrystallization of sedimentary materials under the influence of elevated temperatures and pressures, and reactions between those materials and emanations introduced, possibly often in comparatively small amounts, from a subjacent magma. Reactions and recrystallization doubtless continue concurrently.

" An attempt should be made to distinguish between assimilation and granitization. In the first of these, magmatic fluids are in excess and dissolve or absorb sedimentary rocks . . . . either by ' melting in ' or reacting with them before crystallization. In the other, the granite is formed in place, by reaction between magmatic fluids and the solid minerals of the sediments. Solution and recrystallization go on concurrently ; no large part of the mass is liquid at any given time ; most of the magmatic emanations, in fact, may be gaseous. The amount of the material added from the magma may actually be relatively small, so that the process may be only replacement."

Granitisation has been defined by Malcolm MacGregor and Gilbert Wilson (" On Granitisation and Associated Processes," *Geol. Mag.*, vol. lxxvi, 1939, p. 194) as follows :

" We define granitisation widely as *the process by which solid rocks are converted to rocks of granitic character ;* this includes all such processes as *Palingenesis, Syntexis, Transfusion, Permeation, Metasomatism, Migmatization, Injection, Assimilation and Contamination*, as used by various authors, but rarely with well defined meanings."

Another general statement, especially valuable since it comes from a geologist not overwhelmingly interested in granitisation, can be assembled from a discussion by L. C. Graton (" Nature of the Ore-forming Fluid," *Econ. Geol.*, vol. xxxv, 1940, pp. 301-2). The composite statement is :

" The aureoles of granitization, employed in the usual broad sense which does not require that the parent magma or the resulting product necessarily possesses the exact composition of a true granite, ... represent the transformation of all sorts of earlier rocks into material of such granite-like composition and texture that in many instances it has previously been mistaken for normal intrusive rock."

In his discussion of the granite problem, P. Niggli (" Das Problem der Granitbilding," *Schweiz. Min. Petr. Mitt.* xxii, 1942, p. 28) stresses that granitisation and felspathisation are used to cover the products of many different processes, the chief of these being :

(i) Mineralogical and textural changes, by the development of a granular texture with newly formed felspar ; pure recrystallisation has taken place without change in the bulk composition of the rock.

(ii) The transformation of rocks into ' granite-like ' rocks by recrystallisation, combined with pneumatolytic-hydrothermal transfer of material as, for example, alkalies.

(iii) Granitisation by injection-processes.

(iv.) Granitisation by ultrametamorphism, as, for example, of sedimentary rocks, combined with melting and transfer of material. Palingenesis is a border-line case of this type of granitisation.

It will be an advantage to formulate a definition of granitisation as free as possible from genetic controls, speculative and otherwise. Possessing such a broad and acceptable foundation, each of us may build our solid and everlasting edifices, or our ramshackle and ephemeral hovels, on our own particular corners of it. In its broadest and simplest sense, shorn of all genetic limitations, granitisation means 'the process by which solid rocks are converted to rocks of granitic character,'—to use the words of MacGregor and Wilson. We may meditate on two aspects of this simple statement. First, it implies that there are granites which are not the product of granitisation, for there must be a standard granite for comparison which is not of this parentage. The standard granites are presumably those formed by the consolidation of granitic magma—the Granites of Authority, dealt with in my Address of last year. As I did then, I again make a plea to you not to regard the existence of such granites as an article of blind faith. Rather, for the purposes of this discussion, let us cautiously assume that igneous granites have been identified as such by authority. It is with granites having this kind of validity that the products of granitisation are compared.

Examination of the second aspect of the definition given by MacGregor and Wilson indicates that some genetic limitation is there necessary. Unless we suppose that all magmas are relics of the primitive liquid shells of the early earth, we have to admit that magmas arise by liquifaction of solid rocks. Granites of igneous origin would therefore comply with the definition. We may recall the statement of Hutton : "Nature has formed the granite on the same principle with that of any other consolidated stratum ; so far as the collection of different materials, and the subsequent fusion of the compact mass, are necessary operations in the preparation of all the solid masses of the earth." We may remember the various proposals for the production of granitic magma by the melting of the sial. In all these proposals, ancient and modern, solid rocks are converted to rocks of granitic character, but through an intermediate magmatic stage. It is this genetic limitation that has to be added to the definition of granitisation given by MacGregor and Wilson so that the field of our present enquiry can be within manageable compass.

I therefore add an amendment and would define granitisation thus :

Granitisation means the process by which solid rocks are converted to rocks of granitic character without passing through a magmatic stage.

A definition by Grout ("Formation of Igneous-looking Rocks by Metasomatism," *Bull. Geol. Soc. America*, vol. 52, 1941, p. 1540) :

> "Granitization includes a group of processes by which a solid rock (without enough liquidity at any time to make it mobile or rheomorphic) is made more like granite than it was before, in minerals, or in texture and structure, or in both."

is somewhat similar, but has implications which I cannot accept. I propose to enquire now whether granitisation has happened or not by examining specimen proposals and debates of differing degrees of relevancy.

III. THE FRENCH SCHOOL.

The differences, often profound and constant, between national schools of geological thought would form a study of surpassing interest and entertainment. One branch of this study would be concerned with the cleavage between the French and Germans on what happens at granite contacts. For over a century French geologists have consistently advocated granitisation in one form or another at such contacts. Modern advocates of the process often forget the debt they owe to this great French school: they should 'look unto the rock whence they are hewn, and the hole of the pit whence they are digged.' Accordingly, I display here a selection of the greatest of the French contributions.

As early as 1824 Ami Boué (*Annales des Sciences naturelles*, 1824, p. 41) suggested that heat and emanations coming from the interior of the earth were responsible for processes which we should now include in granitisation. Boué says (I quote from Niggli, *loc. cit.*, p. 23):

> " La chaleur ignée et les émanations gazeuses de l'intérieur de la terre auraient donné aux schistes peu à peu et sous une plus ou moins forte compression une espèce de liquéfaction ignée . . . . Les éléments des schistes auraient perdu de leur force de cohésion, leurs parties constituantes auraient été écartées les unes des autres, et les émanations gazeuses auraient pu s'insinuer dans les vides ainsi laissés. De cette manière les affinités chimiques auraient pu s'exercer dans certaines limites, posées par les forces adverse de la cohésion, et les parties constituantes des roches auraient pu prendre pendant la liquéfaction et le refroidissement lent un arrangement plus ou moins crystallin suivant les circonstances, et sans déranger ou détruire notablement la structure feuilletée, primitive. De plus, le jeu des affinités chimiques aidé par les substances etrangères, introduites, pour ainsi dire, par sublimation dans ces roches, auraient donné naissance à cette foule d'espèces minérales crystallines, qui sont disséminées en nids, en amas et en petit filons au milieu des schistes crystallins."

In the eighteen-thirties, felspathisation and connected topics were touched upon by the master hand, by no means yet come to its full power, of J. Fournet of Lyons (*Neues Jahrb.*, 1837, 1838; see P. Niggli, *loc. cit.*, pp. 25-6). Fournet considered that among the metamorphic rocks are some that result from simple recrystallisation and others from partial melting, combined on occasion with emigration and immigration of material. He realised that rocks very much alike may be of diverse origins; a gneiss, for example, may be of eruptive origin and come as molten material from deep in the crust, but a very similar rock may arise by the modification of a sediment. He asked the fundamental question: how shall we decide whether this or that gneiss is a molten rock or a clayey rock which has been felspathised and crystallised with the formation of mica? Back comes the answer at once—an answer that we, an association of geologists, should cherish; it is the geological relations which make our decision much easier. This answer has served as my text for many exhortations during the last few years when I have stressed the overwhelming importance of the *geological* evidence in all problems of granitisation, migmatisation, contamination and related processes. In a recent discussion at the Geological Society, whose hospitality we enjoy today, I propounded what seems to me the trite and obvious doctrine that the strength of cases of this nature is the strength of the geological evidence; you can accept this evidence on faith in the observer or you can make a pilgrimage to see it for yourself—you can follow Desmarest's (I believe) century-old advice to *go and see*. What you must not do, however, is to remain meek when confronted with a non-geological argument that appears to conflict with the geological evidence. It is true that the meek shall inherit the earth, but the earth is already the geologist's.

The next major development in the French body of thought on these matters was the concept of mineralisers, *agents minéralisateurs*, formulated by H. Ste-Claire Deville in 1841. As Deville's original concept has been elaborated and extended during the century of its usefulness—such elaborations and extensions being indeed a measure of this usefulness—it will be as well to present the original definition (*Comptes rendus*, lii, 1841, p. 1264). It is as follows:

> " Parmi les matières gazeuses que nous rencontrons dans la nature, il en est quelques-unes qui, sans se fixer sur aucune des substances qu'elles touchent, les transforment ou les transportent en les transforment en matières minérals, absolument semblables à celles que l'on rencontre dans la nature. . . . Ce sont ces substances que je propose d'appeler *agents minéralisateurs;* je les caractérise par cette perpétuité de leur action que se continue indéfinement, jusqu'à ce qu'elle soit fixée par des matières autres que celles sur lesquelles elles sont appelées à réagir pour ainsi dire

par leur seule présence. Ces substances, quand elles existent dans la nature, ce qui permet de les faire entrer dans les hypothèses de la géologie, sont toutes compatibles avec l'eau qu'on rencontre en effet partout, et l'eau n' annule et n'amoindrit jamais leur effet spécial."

In order to illustrate the next stages in the evolution of the French ideas I cannot do better than analyse the relevant contributions appearing in the 1847 Bulletin of the Geological Society of France (*Bulletin de la Société Géologique de France*, vol. iv, 2nd Series, 1847). This volume contains contributions of fundamental importance to our present inquiry by such a galaxy as Virlet d'Aoust, Élie de Beaumont, Durocher, Fournet and Scheerer. We may glance briefly at certain aspects of these—I leave the contemplation of the finer points of the swordplay of what developed into a pentagonal duel of some sprightliness to the interested student of French character.

For some twenty years, Virlet d'Aoust had been much concerned, both in Greece and in France, with contact-phenomena of an intense kind and with the production of granite and porphyry by metamorphic processes. In 1844 he had presented his *Note sur les roches d'imbibition* (*Bull. Soc. Géol. Fr.*, vol. l, 2nd Series, 1844, p. 845), in which he had described in a general way phenomena of soaking and penetration by igneous materials of sedimentary country-rocks. His notions and his terminology have influenced French thought to this day. I take this opportunity of making my *amende* to Virlet's manes in that in a mood, transient I trust, of mealy-mouthed decorum I preferred to use another term than imbibition for similar processes in the Central Sutherland complex; perhaps the confine of a Government publication sobered me. In the 1847 volume that we are examining, two contributions of Virlet's are of interest to us. A long footnote (pp. 297-8) in a short glacial paper is devoted to a summary of his views on the origin of metamorphic porphyry and imbibition-rocks. His second contribution (pp. 498-505) has the arresting title, *Observations sur le métamorphisme normal et la probabilité de la non-existence de véritables roches primitives à la surface du globe.* We may examine this more closely.

Virlet begins by making approving references to certain aspects of the views of Fournet and of Scheerer. Both these masters were immensely interested, as were Durocher and many another at this time, in the sequence of crystallisation in granite. Minerals of high fusion point appeared to crystallise after minerals of lower fusion point; Fournet explained this by evoking *sur-fusion*, a sort of undercooling, whilst Scheerer proposed that the granitic paste, "une bouillie, épaisse et humide," before its solidification, was impregnated with water and so crystallised at lower temperatures than a dry melt (p. 492). Virlet remarks that the water contained in sediments will obviously be available when they are made into gneiss and granite.

Virlet introduces the term *granitification* with the following statement :

> "Le transmutation des roches sédimentaires en granite, ou leur *granitification*, pour employer un mot qui caractérise le phénomène, n'est donc pas plus difficile à admettre que leur changement en gneiss ; il suffit seulement de supposer ou que l'action métamorphisante a été plus directe et plus intense, ou qu'elle a été plus prolongée" (pp. 499-500).

Granitification, decides Virlet, does not necessarily require a high temperature. This is indicated by the preservation of stratification structures in, for example, the Brittany granites, as can be demonstrated by inspection of the Paris pavements of blocks of these granites in which countless fragments of country-rock are enclosed (p. 501). This appeal to the Paris pavements is one that Virlet had made before and which was to be echoed by Delesse (Études sur le Métamorphisme des Roches, 1858, p. 316) in 1858 and Michel-Lévy in his classic Flamanville paper of 1893-4 (p. 9). Virlet (p. 144) maintains that the best way of studying granites and what we should now call xenolithic rocks generally is by inspection of pavements, especially, as Michel-Lévy was to say later, *les jours de grande pluie*. Virlet gives this advice because " une cassure brute ne le laisse apercevoir ni aussi nettement ni aussi distinctement que sur les dalles qui ont reçu un certain poli par suite du piètinement, surtour quand celles-ci sont mouillées. Il suffit donc, je crois, de parcourir les rues de Paris, après une forte pluie . . . ." I here allow myself to succumb to the temptation to another of my many digressions.

Intensely detailed studies, after the " micropetrological school of Heidelberg," have of course their place in the investigation of granites, migmatites and so forth. But more important, to my mind, are studies of the largest possible clear rock-surfaces whether natural or artificial. Nowadays we do not have to wait for our large specimens to receive " un certain poli par suite du piètinement." There are provided, free to us, but at great cost to the brewers, bankers and other followers of Balbus, large and beautifully polished slabs of the most exciting stones. Every city has on free display magnificent examples of granitisation and migmatisation. I suggest to members of this Association resident in cities that they should track down, record and describe the more outstanding of the polished slabs on public view. In London, for example, there are available great expanses pertinent to this address along Fleet Street, Victoria Street, Knightsbridge and Brompton Road—to name only a few of the better displays. The best samples known to me are provided by the pillars of St. Columba's Church, Pont Street, and by twelve columns disposed about the green in Parliament Square—these latter are known to my students, and rightly, as the Twelve Pillars of Wisdom. During the bombing of London I watched anxiously for the detachment of specimens of more portable size from the finer exhibits, but without success; indeed, I formed the opinion that the safest procedure in a London blitz was to clasp one of the prize columns to your bosom—neither you nor it would be so much as chipped.

Durocher in his " Note sur une espèce de granite provenant de la Normandie et de la Bretagne," in the 1847 volume, p. 140, criticises Virlet's view that these granites are formed from sediments and contain pebbles of quartz; the alleged pebbles are quartz nodules, due, Durocher says, to accidents of crystallisation. Virlet replies that no segregations occur in these granites, but that there are great quantities of fragments of sedimentary origin in them and maintains that some of the siliceous fragments retain their original marine-pebble shape. We need not discuss Virlet's last contention, but we may note the existence so long as a century ago of a sharp division of opinion on the origin of certain enclaves in granites—by some they are considered to be segregations, by others xenoliths. This discussion still persists; it is maintained by the fundamentally different views concerning the origin of granite advanced by the opposed schools. If we wish to keep the granitic magma as pure and undefiled as possible, then dark blots in the granite are thought to " result from some obscure process of segregation or secretion " to quote the revealing words of Grout (*Petrography and Petrology*, 1932, p. 61). If, on the other hand, we suppose that granitic magma must, by its very nature, act upon its walls or that granitic magma may be more correctly regarded as granitic migma, then the more blots there are the better—they will furnish the key to the rock's history.

In the 1847 volume there is a translation by Frapoli of an important work by Scheerer, " Discussion sur la nature plutonique du granite et des silicates cristallins qui s'y rallient " (p. 468). Scheerer enquires as to what are the facts which should serve as a basis for a theory of granite. Its plutonic origin has been thought to be shown by its contact phenomena and by the resemblance in its composition to that of some true volcanic rocks (p. 475). In Scheerer's opinion, neither of these are serious proofs of an igneous origin of granite and the problem can only be solved by a study of the intimate structure of the rock itself (p. 476). Such a study indicates that water must take a prominent part in the happenings in the granitic paste which must thus be a " bouillie aqueuse " (p. 489). Scheerer favours imbibition as an important process of metamorphism at contacts (p. 494) and, in discussing the transformation of clay rocks into rocks having the appearance of gneiss and granite, concludes that such a transformation, as observed in Norway, is due to the heating-up of rocks containing water (pp. 494-5).

The greatest figure in geological circles in France at this time, and possibly at any time, was Élie de Beaumont. An excellent sketch of the man, Senator of France and grand seigneur, has recently been given by P. Fallot (" Élie de Beaumont et l'évolution des sciences géologiques au Collège de France," *Ann. des Mines*, vol. xv, 13th Series, 1939, pp. 75-107), whilst an account of his work, including a summary of his 1847 essay on emanations which we examine in a moment, appeared in C. Ste-Claire Deville's volume *Coup d'oeil historique sur la Géologie et sur les travaux d'Élie de Beaumont*, Paris, 1878. Author of some 250 geological works, Élie de Beaumont dealt in a masterly fashion with all branches of the science. We can here occupy ourselves with only one contribution, his *Note sur les émanations volcaniques et métallifères*, which occupied pp. 1247-1333 of the 1847 volume of the Geological Society of France. As Fallot has remarked, this classic paper laid the foundations for the modern study of mineral deposits; I can deal here only with such parts of it as are relevant to my topic today.

The first point in Élie de Beaumont's work to which I direct attention is one of great interest to our present discussion. On several lines of evidence he concluded that there are two fundamentally opposed groups of eruptive rocks : first, the basic group which is dominantly volcanic, but includes also traps and serpentines, and secondly, the acid group which is dominantly plutonic and granitic ; each group is attended by its own cortege of characteristic mineralisers, mineral deposits and constituent minerals (pp. 1253, 1254, 1288). There are fundamental differences in the mode of eruption of granites and of other eruptive rocks (p. 1297). These statements of de Beaumont's are an early expression of the views on the volcanic and plutonic associations of eruptive rocks put forward recently by Kennedy and referred to in my Address of last year.

The emanations with which de Beaumont is concerned are considered to be volatile substances capable of transporting silicate and metallic materials beyond the active zone of heat and, since they can clearly penetrate through the finest pores and spaces in rocks, they must be in the form of vapours or solutions. They take their origin, together with the lava which brings them to higher levels in the crust, in the internal furnace of the earth (pp. 1250, 1274, 1275, 1281, 1288).

The action of these emanations is especially well seen in and around granites with tin lodes attached to them. There is a community of elements characteristic of the granite, the tin lodes and the metamorphosed country-rocks. Thus arises an *aura granitica*, or a *pénombre du granite*, to recall Humboldt's phrase, in which chemical reaction and physical crystallisation have proceeded with extraordinary energy ; this leads to the exaggeration at the granite margin of the granitic characters so that there arise " dégradations ou monstruosités de granite " such as pegmatite, graphic granite and greisen. The emanations must be in the form of a singularly active and tenuous vapour since they are able to transport very refractory substances and to produce great changes in the country-rocks (pp. 1295, 1296, 1314, 1315).

Granites are so often characterised by marginal passages to gneiss and mica-schist that the origins of all these crystalline rocks must be closely connected

(p. 1301). De Beaumont accepts Virlet's proposals that some granites are of metamorphic origin and discusses how such granites can yet display the characteristic minerals of the *aura granitica.* The sedimentary rocks from which the mica-schists, gneisses and granites were formed by metamorphism had been derived, he suggests, from more ancient granites and gneisses, so that the characteristic minerals were obtained at second-hand. This notion of cycles of these characteristic minerals or elements is one that in my opinion may yet play an important part in the elaboration of the granitisation theory. De Beaumont repeats that the origin of mica-schists, gneisses and granites is one connected question ; he says :

> " Ainsi la question de l'origine du granite est à la fois d'autant plus importante et d'autant plus difficile, qu'elle comprend celle de l'origine de plusieurs des roches cristallines les plus répandues du globe. C'est une vaste problème dont la question de l'origine du granite est le noeud " (p. 1301).

This profound statement has been forgotten by many a thoroughgoing magmatist. For example, Niggli (*loc. cit.*, p. 7) believes that the association of granite and gneiss *complicates* the granite problem. For some of us, on the other hand, this association may *clarify* the problem. We will resume this debate later ; I now return to Élie de Beaumont for a last point. He distinguishes very clearly between granites with chilled margins and but feeble contact effects and those surrounded by veins and stockworks. The first type evidently possessed *la vertue métamorphisatrice* to only a small degree and lost at their contacts the faculty of granitoid crystallisation—" ils étaient, pour ainsi dire, *éventés.*" In their mode of emplacement and in their poverty in mineralisers, they resembled the quartz-porphyries and the basic group. This difference in the marginal relations of granites is a fundamental aspect of the granite problem and its recognition is by no means the least of Élie de Beaumont's contributions to petrogenesis.

The last of the masters of the 1847 volume that I have to consider is Fournet, whose early views I have already noted. In his paper, " Résultats sommaires d'une exploration des Vosges," pp. 220-254, there are certain results of great importance to this discussion. Fournet, in agreement with Élie de Beaumont, is very clear that the metamorphism brought about by granites is due both to the heat that they have made available and to the ' principles ' necessary for metamorphism that they have furnished to the country-rocks (p. 230). He distinguishes between eruptive porphyries and metamorphic porphyries, and in his discussion of the origin of the latter type mentions such ideas as the capillary soaking of metamorphic rocks by igneous liquids, the saturation of country-rocks by the porphyritic paste, and the formation of porphyritic rocks by imbibition with concomitant loss of fissility by original sediments (p. 239). He realises that if packets of country-rock float in an igneous bath their lower parts will be dissolved and according to their nature thus impress *une physionomie spéciale* on the plutonic rock. Comparable operations are commonplace in the chemical laboratory. A lump of sugar, half immersed in water, he recalls, draws up a certain amount of water into its upper parts and at the same time the excess water becomes charged with sugar. Are plutonic rocks to be placed outside the general rule ? ; " seraient-elles des corps exceptionnels ? " If they are exceptional bodies then

> " tous nos raisonnements, tout le laborieux enfantement du métamorphisme par des effets de contact, de capillarité et de confusion, n'auraient abouti qu'à la production d'une vaine chimère à placer à côté des vapoureuses rêveries auxquelles se laisserait aller une science encore dans son enfance " (pp. 241-2).

Happily, says Fournet, this is not the case. Caution, however, is needed. Transitions of one rock into another allow us to make certain genetic conclusions, but the fundamental characters of the three great groups of rocks—igneous, sedimentary and metamorphic—remain unimpaired ; if it were otherwise we should fall into the ancient errors and see passages from granite into coal, porphyry into sandstone, basalt into shelly limestone.

These statements of Fournet's lead me to two points. First, he saw very clearly that plutonic rocks were not emplaced as it were in platinum crucibles—there must be reaction at the walls. Secondly, he uttered a warning against excess of enthusiasm for rock transformations which should be taken to heart at this present time. Great damage is being done to the general hypothesis of granitisation, for example, by the uncritical application of the proposal ; we need, sometimes, saving from our friends.

After the general discussion which I have indicated above, Fournet deals in particular with the porphyries of the Vosges. He concludes that the metamorphosed rock has influenced the metamorphosing rock ; there has been reciprocity of action. This leads him to one of his most important proposals. *Metamorphism*, he states, is the totality of effects in both the plutonic and country rock at contacts ; modifications of the plutonic rock are *endomorphism*, of the country-rock are *exomorphism* (p. 243). He thus supplied two terms which have remained peculiarly French as have, I am afraid, the ideas which underlie them. For Fournet and his contemporaries then, it was to be expected that plutonic rocks should be modified in structure and in composition by reaction with the country-rocks—they could thus acquire *une physionomie spéciale*.

In this same *annus mirabilis*, 1847, there appeared the German translation by W. Vogelgesang of a remarkable work of Fournet on metamorphism. The translation is entitled " *Die Metamorphose der Gesteine nachgewiesen in den westlichen Alpen* (Freiberg, 1847) and is prefaced by an introduction by B. Cotta which is worthy of notice. Cotta admits that a sedimentary pile, if thick enough, must come within the influence of the earth's internal heat, and may be melted to give eruptive rocks which would produce contact metamorphism. Large granite masses must act in a similar fashion, though on a smaller scale, to the hot interior of the earth and so give rise to crystalline schists and even eruptive rocks. Cotta regrets, however, that he cannot remember finding rock transformations of this special kind on any great scale.

Fournet describes, amongst other phenomena, complex veining of country-rocks, transitional zones between country-rock and eruptive rock (p. 6), felspathisation, impregnation of country-rock (p. 12), and the growth of porphyritic felspars in hornstone (p. 13). His theoretical discussion contains abundant material of great interest to students of metamorphism. He attempts, for example, some kind of zoning in his metamorphic rocks ; he endeavours to zone the metamorphism of clay-slate on colour, but cannot get far (p. 37) ; by considering the state of the various bituminous rocks of the Western Alps, he deduces a kind of zonal arrangement for them about a central plutonic axis, that is, an axis of access of the earth's internal heat—but finishes by pleading for more information (p. 36). Surely this must be one of the earliest explorations of metamorphic zoning.

Fournet discusses the results of plutonic action on slaty rocks. He notes that since clay-slate contains potash, soda and lime it is possible for felspars to arise by simple recrystallisation. In some cases, however, so much felspar is developed that an impregnation with felspar, by some kind of capillary action, must have taken place (p. 72). He goes on to distinguish two kinds of process in the formation of these special contact rocks—a distinction which we shall see later has played an important part in the subsequent development of French ideas on granite contacts. Fournet distinguishes between *injection*, in which veinlets are inserted along foliation planes, and *capillary soaking* of hot fluids into the lamellae of the country-rock (pp. 73-4). The materials involved in the soaking permeate the country-rocks with extraordinary ease and must lead to important chemical reactions in them (p. 76).

Finally, Fournet shows that the degree of metamorphism is related to the proximity of a plutonic hearth (p. 97). Metamorphism is, however, so widespread in many regions that it is rather difficult to relate it to eruptive bodies which have brought in the heat and materials necessary for metamorphism. According to some, it appears much simpler to permit a stream of hot gases to perform the rock transformations that are observed (p. 98).

So much for the year 1847. We have seen the planting then of a great variety of seeds. Some have parched and perished, others have germinated and have grown into the brightest flowers of French geology. Before I pluck a bunch of these I have to record the nurture of the tender plants by many a French geologist—I select Delesse for a brief enquiry.

In his *Études sur le Métamorphisme des Roches*, 1858, Delesse separated two great classes of metamorphic phenomena, those of normal or general metamorphism (our regional metamorphism) and those of abnormal or special metamorphism (our contact or thermal metamorphism). In contact metamorphism, dealt with in this 1858 volume, the responsible agents are heat and gases, vapours or solutions (p. 3), but the effects of heat have been exaggerated (p. 10). He notes that at granitic contacts, contact metamorphism confuses itself with regional metamorphism (p. 5). His treatment of such contacts follows of course the French mode. Among other matters of interest he describes, from the pavements of Paris, the development of granite minerals in fragments of country-rocks and recalls that Cotta had noted in 1857 the growth of large crystals of orthoclase in dioritic fragments in the Thuringerwald granite (p. 316). Similar felspathisation is recorded in the St. Gotthard area, in Norway, in the Vosges and elsewhere (pp. 362-4). In many cases, pelitic sediments pass by a process of felspathisation into "*un véritable porphyre granitoide*"; when the felspar developed is orthoclase, it is usually accompanied by the minerals of granite—"dans ce cas, suivant l'expression consacrée par Keilhau, le métamorphisme est caractérisé par une *granitification*" (p. 364). This kind of metamorphism is usually on a grand scale and merges into regional metamorphism (p. 364).

In his 1869 *Études sur le Métamorphisme des Roches*, Delesse considers his general metamorphism or our regional metamorphism. During this consideration he advances ideas on the plutonic rocks which are of fundamental interest in this present discussion. His most important proposal is that the plutonic rocks are the result and not the cause of metamorphism. Thus :

> "Les roches plutoniques se sont formees aux depens des roches métamorphiques, et elles représentent le maximum d'intensité ou le terme extrême du métamorphisme général" (p. 88).

When plutonic rocks occur in veins they cause little metamorphism and that little is special metamorphism in Delesse's sense; when they occur in large masses, however, they pass insensibly into the neighbouring rocks and have great zones of metamorphism about them. Metamorphism with low energy gives rise to slates and similar rocks, whilst metamorphism with high energy gives rise to high grade metamorphic rocks *and* plutonic rocks (pp. 88, 89). Delesse then makes the following observation—an observation linking earlier views such as those of Élie de Beaumont, with certain developments which we consider later :

> "Ces dernières (i.e., the plutonic rocks arising through metamorphism at high energy levels) qui jouissaient d'une plasticité plus grande se sont très-souvent comportées comme des roches éruptives. Elles ont été ramenées vers le surface du sol par des pressions intérieures . . . Mais alors elles ne sont plus en contact aves les roches métamorphiques qui leur correspondent, ni avec celles aux depens desquelles elles se sont formées ; c'est, du reste, le cas le plus habituel" (p. 89).

That is, cross-cutting granites at high levels in the crust may have lost all evidence by which their real origin can be determined—a pleasing thought, indeed.

During the last quarter of the nineteenth century the French school blossomed in the work of Michel-Lévy, Lacroix, Barrois, Duparc and others. When nowadays geologists refer to the French School of granitisation, using this term in a broad sense, it is the products of this period that they have in mind but, great though its achievements then were, they were possible only because they were developments from the experience of the earlier parts of the century. Injection, imbibition, assimilation and the like had become part of the French geological mind. It was therefore in a congenial atmosphere that Michel-Lévy and Lacroix in particular produced those embellishments of the French corpus which we shall examine immediately. Before we do that, however, I should recall that these were the times when, outside France, the " micro-petrological school of Heidelberg "—to use Sederholm's term—headed by its world-famous leader Rosenbusch and supported by industrious cohorts from many European and American satellites marched in its greatest array. The temporary conquests of this school were innumerable and extensive. We should remember in particular at this time that the French citadel of " granitisation " maintained itself inviolate against all assaults, largely because of the brilliant sallies of Michel-Lévy and Lacroix. We have opportunity here to examine in detail only two campaigns, first that of Michel-Lévy, of the line of Élie de Beaumont at the Collège de France, and then that of Lacroix of the Muséum.

I select for special remark only one of the many great contributions of Auguste Michel-Lévy—the Flamanville classic (" Contribution à l'étude du granite de Flamanville et des granites francais en général," *Bull. Carte Géol. Fr.*, vol. v, 1893-4). At Flamanville in the Cotentin, on the western shore of the Cherbourg peninsula, Palaeozoic sediments are invaded by a small mass of granite which supplies well-displayed contact-phenomena.

Michel-Lévy, following his forerunners in the French School, records the two types of contact-process, *par injection et par superposition*, and defines them in the following terms :

> " Par injection parce que les petits fillonets feldspathiques injectent lit par lit la roche schisteux préalablement transformée en schiste micacé ; par superposition lorsque les éléments du granite de plus grosse taille, font pour ainsi dire éclater les éléments du schiste micacé et en englobent les débris sous forme d'inclusions " (p. 4).

At the contacts the Silurian sediments are transformed into felspar-bearing rocks and pass into gneisses and micro-granites (p. 6), whilst the granite itself becomes endomorphosed with the development of a schistose texture and the appearance of ferromagnesian minerals in quantity (p. 9).

Armed with his experience of other granite contacts and refreshed by these Flamanville displays, Michel-Lévy proceeds to discuss granites in general. As a preliminary, he declares (p. 17) that structure (i.e., texture) and mineral composition are the only factors necessary for rigorous definition—a declaration worth pondering. What happens at granite contacts next occupies his attention. The dominant agents here are the mineralisers which act differentially on the various country-rocks (pp. 18, 21). At the immediate contact the effects of transfer of material are visible to the naked eye; there then arises a zone of felspathisation in which gneisses of various kinds are found (p. 21). From the French experience it is certain that the views of Rosenbusch that felspathisation does not occur at granite-contacts and that gneisses are not formed in such contacts, are demonstrably wrong (pp. 21-2).

This felspathised zone has great theoretical significance; in it are found, synthetically reproduced as it were, all sorts and conditions of crystalline schists and in many cases these varied crystallines can be related to varying beds of country-rock. Michel-Lévy records that Barrois had provided in the then not yet published accounts of the Brest and Morlaix Sheets irrefutable examples of the transformation of entire regions of Pre-Cambrian beds into gneisses by granitisation. Bands of quartzite, more resistant to felspathisation, can be traced in the midst of more argillaceous rocks which have been converted into gneisses. " La stratigraphie vient donc ici affirmer l'équivalence de vrais gneiss avec des schists franchement clastiques, dont la transformation est due au voisinage de massifs granitiques " (p. 23).

The study of enclaves in granites reinforces these conclusions. But a new and most significant fact emerges from this study. Great crystals of orthoclase, " *dents de cheval*," are found in the enclaves identical with those which at times give a porphyritic appearance to the surrounding granite. Sometimes these crystals are scattered through the enclave, sometimes they orient themselves in accord with the schistosity, which has already been designed by the disposition of the granulitic and biotitic elements. Such a *gneiss glandaleux* cannot be formed, as Rosenbusch vainly thinks, by dynamometamorphism since the granite itself is not laminated (p. 23).

This skirmish with Rosenbusch is resumed later (pp. 28-29) in connection with the interpretation of marginal schistose varieties of granite found at many contacts. These were considered by Rosenbusch and his followers to be the result of dynamometamorphism; Michel-Lévy shows that they are due to impregnation of originally schistose rocks by granitic elements—the schistosity in the granite is relict from the sediment. Michel-Lévy demonstrates this by three lines of evidence, first the similarity between such schistose granites and certain enclaves, second the marked chemical changes which are inexplicable by dynamometamorphism and lastly the great differences which exist between these schistose marginal granites and those, as for example, from Mont Blanc, on which dynamic metamorphism has admittedly operated. I detail these arguments because even now the Rosenbusch position is maintained in some strength. A point demonstrated by Michel-Lévy by comparative studies of granites in the Morvan, Beaujolais, Auvergne and Mont Blanc is that the felspathised zone around granites increases with depth until the contact-zones in some measure become zones in which granitic rocks are made (pp. 22, 24).

We have already noted that Élie de Beaumont and others of his time clearly recognised a fundamental distinction between the basic and volcanic rocks on the one hand and the acid and plutonic on the other—early expression of the idea of Volcanic and Plutonic Associations. Michel-Lévy stresses this distinction. In his major polemic against Rosenbusch, his *Structures et Classification des Roches Eruptives*, 1889, p. 84, he had rejected the view of any direct relationship between the granitic rocks of the depths and the volcanic rocks of the surface. The volcanic chimneys had nothing to do with the *appareils granitiques* (Flamanville, p. 34). He underlines this conclusion:

> " Nous ne saurions donc trop insister sur l'absence de liaison stratigraphique ou pétrographique entre les laccoliths, les vraies cheminées volcaniques avec filons et lits intrusives, d'une part et les gisements granitiques d'autre part " (p. 35).

Michel-Lévy's last topic is concerned with the eruption and *mise-en-place* of granites. Suess' concept that granite batholiths result by the simple filling of spaces arising through tangential movements of the crust is clearly wrong, since it is a fact that granites enlarge themselves downwards and " gagnent aux dépens des formations cristallophylliennes voisines qui deviennent, elles aussi, de plus en plus cristallines et granitiques " (p. 36). Study of favourable exposures, such as that of the great quarry of Diélette at Flamanville, shows that granites make their way very slowly without disturbance of the invaded strata. " Tout milite en faveur d'une tombée en fusion, en liquation, des salbandes voisines, avec assimilation lente et partielle par la roche éruptive " (p. 36). Marginal inhomogeneity arises by the incomplete digestion of a crowd of fragments of country-rocks. Granites are locally charged with very local strata. For example, at several French localities, the granites show nodules of cordierite, still in regional alignment; these nodules are the only relics of the remainder of the country-rocks which have been resorbed in place (p. 36).

It seems, says Michel-Lévy, that the ascent of granitic magma takes place by a kind of fusion, assimilation or corrosion of the surrounding rocks, brought about by heat and mineralisers coming from the magma. First stages are seen in the rejuvenation of quartz and the formation of black mica in the contact-rocks. Then felspathisation takes place, little veins of quartz and felspar are born which increase in number till they are inseparable from the granite and have made mobile all the elements of the contact-schists. Michel-Lévy concludes :

> " En d'autres termes, le métamorphisme de contact se confond peu à peu en profondeur avec le métamorphisme général. Ils unissent leur action et si l'on supposait l'érosion suffisamment profonde, on arriverait au niveau où les magmas granitiques ont dû fondre tous les voussoirs de l'écorce terrestre " (p. 36).
>
> " Il en résulte que les voussoirs affaissés, qui auraient pu leur servir de base,sont plus ou moins assimiliés par la roche éruptive et transformés en gneiss granitiques, puis en granites gneissiques et enfin en granite " (p. 39).

Michel-Lévy, by his work in the field and in the laboratory, gave precision to the proposals of his predecessors of pre-microscopic petrology days. Imbibition, injection, lit-par-lit action, felspathisation, endomorphism, inherited textures, depth-phenomena were elaborated. His greatest contribution, however, was his views on the mode of emplacement of granites by the gradual making-over of the wall rocks until they come to resemble granite and the incorporation of this material in the granitic magma. It is difficult to assess how much of Michel-Lévy's process would come within my definition of granitisation. To him granitic magma is always in evidence at the higher levels, whilst in depth granitic magmas may be formed by the melting of the walls. It is clear, however, that much of his felspathised zone and of his endomorphic granites would comply with my requirement that the magmatic stage has not been passed through.

Of the relevant work of A. Lacroix, I take for consideration the two famous memoirs on the granite contacts in the Pyrenees—" Le Granite des Pyrénées et ses Phénomènes de Contact: Premier Memoire," *Bull. Ser. Carte Géol. France*, No. 64, vol. x, 1898-9; " Deuxième Mémoire," *ibid*, No. 71, vol. xi, 1899-1900. From this study of well-exposed contacts of granite with very varied country-rocks in the High Pyrenees, Lacroix shows the general applicability of Michel-Lévy's conclusions on the contact-phenomena and the mode of emplacement of granites. Lacroix (i, p. 48) contrasts the views of the French, as put forward by Michel-Lévy and himself, with those of the Germans, as put forward by Rosenbusch. It is worth reproducing here, in Lacroix's own words, what the two positions were :—

According to the French (Lacroix i, p. 48) :

> " Les phénomènes de contact des roches éruptives sont le résultat de la transformation d'une roche préexistante, apportant sa caractéristique personelle, sous l'influence d'agents minéralisateurs, le plus généralement accompagnés d'éléments volatils ou solubles qui, en se fixant la roche modifié, en transforment plus ou moins complètement la composition chimique."

According to the Germans (Rosenbusch, *Mikr. Phys.*, 1896, vol. ii, p. 85) :

> " On peut formuler cette loi, que dans le métamorphisme de contact au voisinage des roches de profondeur, la roche éruptive a agi d'une facon purement physique et en général n'a agi chimiquement par l'intervention d'aucune substance. L'analyse chimique des roches de contact dans les divers stades de leur évolution a montré, qu'à l'exception des corps volatils comme l'eau et les substances organiques, il n'y a pas eu changement dans la composition. Tout s'est borné en réalité à une nouvelle répartition des molécules ; la roche éruptive par les conditions de température et de pression dont elle était le foyer en est la cause, alors que la roche sédimentaire en a formi la matière."

Lacroix makes appeal to the only evidence of value, that displayed in the field. He recalls that at many contacts in the Pyrenees described by himself and at many other places in France described by Michel-Lévy and Barrois there is a constant zone of felspathisation by imbibition and by injection at the immediate contact of the granite; in this zone it is possible to follow progressively all the stages in felspathisation and to trace insensible passages between the felspathised schists (leptynolites) and the granites themselves; but even in the most felspathised parts, where true gneisses are formed, there are still recognisable relics of the country-rocks in an intermediate stage of transformation (i, p. 49). Such phenomena are so often seen at French contacts that Lacroix is astonished at the existence of other views. But, he says, " je n'aurai garde de confondre la *possibilité* pour le magma granitique de déterminer des feldspathisations intenses, avec la *nécessité* pour celui-ci d'agir tourjours de la même facon sur les roches sédimentaires en contact avec lui " (i, p. 50). Admittedly, some granites show knife-edge contacts with hornfels zones about them; this variation in type is clearly due to variation in the amount of mineralisers, in the physical conditions at the contacts, and, especially, in the depth. Transfer of material is obvious (i, p. 51). There must, for example, be transfer in the formation of metamorphosed limestones rich in potash felspars (i, p. 52).

Lacroix agrees with Michel-Lévy (*Bull. Soc. Géol. France*, vol. xxv, 1897, p. 326) in considering that magmas consist of two parts, one which consolidates as the ordinary rock-forming minerals, the other, set free when this consolidation occurs, composed of volatile elements which are able to modify profoundly the country-rocks adjacent to deep-seated magmas. It is clear in the Pyrenees granite contacts that the elements contributed to the country-rock when added to the substances already there produce a rock having a composition very near that of granite itself; the solution of this modified material by the granite magma does not alter the composition of the magma. Granite magma is thus the result of the assimilation of schists and is not the original pure magma (i, pp. 56, 57). " Le magma, ayant dissous les schistes, devait avoir la composition du granite consolidé sur lequel sont basées nos observations, augmentée de la partie volatile libérée au moment de la consolidation de la roche " (i, p. 57). If much pelitic rock is dissolved, the granite is over rich in biotite, if calcareous rocks are dissolved the granite is more basic.

The part of Lacroix's Pyrenean work which has given rise to most discussion is that dealing with the endomorphism of granite by limestone. Isolated in the granite, since the non-calcareous rocks have been dissolved, are lenticles of limestone, and closely associated with these are bodies of hornblende-granite, diorite, olivine-norite, hornblendite and hornblende-peridotite—that is, bodies of a variety of plutonic igneous rocks (i, p. 59). Michel-Lévy (*Bull. Soc. Géol France*, xxiv, 1896, p. 123; xxv, 1897, p. 369) had noted a somewhat similar association in the Beaujolais and at Puy du Dome, and had proposed that endomorphism by calcareous rocks had taken place. This process, combined with felspathisation, was considered by Michel-Lévy to play a fundamental role in the evolution of the magmas which give the eruptive rocks; Michel-Lévy's proposal was, of course, entirely opposed to " les diverses théories de différentiation *en vase clos* fort en honneur aujourd'hui parmi les pétrographes "; *en vase clos* is what I have before termed *in platinum crucible*.

Lacroix (i, p. 59) is careful to point out that he does not wish to claim that all this variety of plutonic rocks is everywhere due to the assimilation of limestone by granitic magma, but he rightly insists that his field-observations show that the required transformations are *possible*. Every time, he reiterates (i, p. 60), that one finds a lens of limestone enclosed in the granite, one sees it surrounded by a peripheral zone of rock rich in amphibole, and this amphibole-rich rock is found only around the limestone or on the strike of the limestone outcrops.

Lacroix agrees further with Michel-Lévy's views on the *mise-en-place* of granites by the progressive assimilation of the country-rocks whose place they come to occupy. The retention by enclaves of their original positions in the regional structure is convincing proof of this thesis (i, p. 62). " Dans la vallée de Baxouillade, il est facile de suivre pas à pas l'imprégnation et la gneissification des schistes formant encore par places des traînées continues au milieu d'une roche, qui oscille entre un granite gneissique et un gneiss granitoide à enclaves " (i, p. 63). In these Pyrenean contacts there has thus been no kneading of the complex and the granite has reached its upward limit, the result being that the endomorphosed products still lie beside the enclaves responsible (i, p. 63).

Lacroix emphasises the high validity of the field evidence—*nous pouvons toucher de la main*, he says, and adds that these matters are not *une simple conception de l'ésprit* (ii, p. 26). The gradual ascent of the granitic magma is described as follows :

> " Au fur et à mesure que le magma granitique montait dans les couches sédimentaires, il y était précédé et accompagné par son cortège d'émanations transformatrices et, ce qu'il devait dissoudre pour faire sa place, ce n'était plus les sédiments normaux, mais des roches imbibées, transformées ou en voie de transformation, par fixation des émanations parties de sa propre masse " (ii, p. 26).

Lacroix emphasises the dominance of imbibition over injection in felspathised and granitised zones (ii, p. 27). He emphasises once again the fundamental difference in the behaviour of pelitic and calcareous country-rocks towards the granitic magma ; the former are felspathised until they attain a granitic composition (ii, p. 27) and so, on absorption, cause little change in the magma (ii, p. 29), whereas the limestones, being converted into calc-silicates and not into felspathised rocks, naturally modify the granitic magma into others solidifying as much more basic plutonic rocks (ii, pp. 29-30).

The impatient reader, not appreciating the meandering and leisurely progress of meditations, mine or anyone else's, may protest that I have devoted a disproportionate amount of time to the French school and especially to Michel-Lévy and Lacroix. I reply that I have deliberately considered in some detail the evolution of this school and its fruition in the eighteen eighties and nineties, because the British and American outlook on these matters has up to recently been largely Teutonic. Even some of us who render lip-service to the French school have but a slender acquaintance with its tenets. I have still more to say of this school in the work of Pierre Termier.

In considering the views on metamorphism and plutonic activity put forward by Termier we have to note with some care certain differences between him and his predecessors. To begin with, Termier (" Les schistes cristallins des Alpes occidentales," *C.R. IX Congrès Géol. Internat.* Vienna, 1903 (1904) p. 583-5) held that regional metamorphism is quite another matter than the intensified contact-metamorphism of Michel-Lévy and Lacroix. The intrusion of eruptive rocks is only an episode in regional metamorphism—intrusion and metamorphism are indeed but two effects of the same cause. " S'il-y-a des gneiss dans le Mont-Blanc, et des micaschistes, ce n'est parce que le granite est venu s'installer au milieu de ces strates : mais le granite est venu se former au milieu de ces strates sous l'empire de la même cause qui, de ces strates sédimentaires, faisait des assises cristallines." Regional metamorphism is produced by an oil-spot mechanism, the celebrated *tâche d'huile* mechanism, by which, just as oil spreads unequally through the layers of a pile of different stuffs, so do elements arriving from the depths permeate unequally into the sedimentary layers in the geosynclinal pile (*loc. cit.*, p. 585). Influx of material is clearly operative : " cet apport, je le demande à des colonnes filtrantes, venues d'en bas, et qui montent, comme d'une chaudière, du fond de la région centrale du géosynclinale " (*loc. cit.*, p. 585). The appearance of felspars is undeniable evidence of transfer of material (" Sur la genèse des terrains cristallophylliens," *C.R. XI Congrès Géol. Internat.* Stockholm, 1910 (1912), p. 590). But for the whole series of crystalline schists, Termier affirms, one cannot reasonably doubt that there has been a new influx of material from the depth which has chased in front of it some of the old material (*loc. cit.*, p. 590): this is the " migmatite front " of modern writers. These juvenile vapours, *véritables colonnes filtrantes*, with various gases, silicates and borates of the alkalies, in passing upwards raise the temperature of the surrounding rocks; this rise, with the abundance of solvents, leads to intense chemical reaction; mixtures with low melting points go into solution first, whilst the old elements in excess flee before the *colonne filtrante* and displace other elements in their turn. True magmas are thus formed here and there of all dimensions and increasing in volume with depth. When the whole region cools down, the parts which have become fluid crystallise as massive rocks, granite, gabbro, diorite and so on—each great family of igneous rocks corresponding to a eutectic. In the upper parts of the structure, crystalline schists are formed, whilst the still liquid magmatic portion may be intruded at high levels in cross-cutting fashion (*loc. cit.*, pp. 592-3).

For Termier, then, the production of igneous rocks is only an episode in regional metamorphism. The sole criterion of abyssal formation is the amplitude and intensity of the metamorphism which surrounds the igneous rocks and which at first sight *seems* to emanate from them. If a granite is surrounded by a narrow aureole, it is certain that the granite has not been made in situ—it has come from somewhere else, ready made. If, on the other hand, a granite is surrounded by a vast aureole of metamorphic rocks, it has certainly been formed in place, by complete fusion of a eutectic, whilst the neighbouring rocks were regionally metamorphosed.

The chief difference (and this only for certain levels) between Termier, on the one hand, and Michel-Lévy and Lacroix on the other, is concerned with the status of the granite magma. For Termier it is generated by an intensification of the processes giving the crystalline schists and gneisses ; for Michel-Lévy and Lacroix the granite arrives from the depths and is responsible for the extended metamorphism around it. It seems to me that the views as to what happens deep in the structure become confluent, as do in fact the fields of contact and regional metamorphism.

Modern French geologists, for example, Demay, Raguin, Longchambon, Jung, Roques and others, whilst in some respects elaborating the classic French views, have much in common with the Fennoskandian workers whose results I examine immediately. Regretfully, then, I can do here no more than recommend their writings to your consideration.

As I see it, the great contributions of the French during the last century have been these. First, they have made the geologist (if he does not keep his mind *en vase clos*) familiar with the notion of emanations, mineralisers, volatiles and so forth as agents of immense importance in metamorphic and plutonic phenomena. Secondly, they have dissected and interpreted granite-contacts in such perfection that their century-old notions, and even their terminology, are still current. Thirdly, they have refused to believe that magma does not act upon its wall-rocks and have demonstrated reciprocal exomorphic and endomorphic operations of great significance. Fourthly, they have shown the existence of many kinds of granite-contacts, some sharp and some hazy, some with no transfer and some with immense transfer, and have thus displayed the unity of granite phenomena. In doing this, they have freed us from the illogical constraint of the gross extrapolations of Rosenbusch and his followers. Compare the beauty and fruitfulness of the French concept of the relations between depth and character of granite contacts with the barren frigidity of the Barr-Andlau master. Fifthly, they have considered the association of metamorphic rocks, gneisses, mica-schists, etc., with granites as of genetic significance and not as unnecessary complications. Sixthly, they have realised the significance and importance of felspathisation as a petrogenetic process. Seventhly, they have advanced a mechanism for the emplacement of granites which solves the otherwise insoluble room-problem of granite intrusion. Lastly, they early appreciated the fundamental difference between the dominantly basic and volcanic association on the one hand and the dominantly acid and plutonic association on the other. This is a record which should make any man, French or not, proud to follow even at a distance.

IV. THE FENNOSKANDIAN CONTRIBUTIONS.

In this section of my remarks I propose to place before you certain contributions by those masters of the migmatites, the geologists of Finland, Sweden and Norway. As I wish to deal more particularly with recent results from these countries, I have no opportunity to consider the views advanced for example by Keilhau and Scheerer over a century and by Kjerulf and Reusch over half a century ago. I begin with Sederholm.

In the first part of these Meditations on Granite (*Proc. Geol. Assoc.*, vol. liv, 1943, pp. 75, 80) where I discussed the granitic magma and its origin, I considered various aspects, concerning migmatites, ichors, anatexis, palingenesis and so forth, of the researches of the great Finnish geologist, J. J. Sederholm (1863-1934). Sederholm's chief work is contained in four memoirs of the Commission Géologique de Finlande, and interim reports, summaries and discussions of his are numerous in various non-Finnish publications. The four memoirs we are concerned with are, first, the classic " Om Granit och Gneiss," *Bull. Comm. Géol. Finlande*, No. 23, 1907, written in Swedish but with an English summary of 20 pages, and second, the three volumes in English " On Migmatites and Associated Pre-Cambrian Rocks of South-western Finland," No. 58 (1923), No. 77 (1926) and No. 107 (1934)[1]. This last memoir, No. 107, was edited and published after Sederholm's death by Erkki Mikkola, who himself perished in the first Finnish-Russian war. These four memoirs are illustrated by hundreds of figures of rock-surfaces which display the astounding complexity of the Finnish Pre-Cambrian, so that merely to turn over their pages provides a liberal education on the possibilities of migmatisation. Here, however, I have opportunity to deal only with such parts of Sederholm's work as are necessary for the present inquiry. I leave his dissection of the Finnish granitic complexes for your study.

As appears to be also the case with Michel-Lévy and Lacroix, nowhere, as far as my knowledge goes, does Sederholm explicitly define granitisation, though he uses the term dozens of times. He refers for example to Michel-Lévy's *granitization theory* (*Migmatites* I, 1923, p. 5) and proclaims himself to be " one of the most eager partisans of the granitization theory " (*ibid.*, p. 13). We have therefore to endeavour to extract from his writings what he understood by granitisation ; I believe this can be done reasonably and fairly. In practically all cases, granitisation was to Sederholm a process clearly connected with granitic magma and was caused by it : thus, " phenomena of granitization caused by not less than five different granites " (*ibid.*, p. 17) ; " granitization phenomena of Hangö granite " (*ibid.*, p. 100) ; " it is sometimes difficult to say whether the granitization is due to Vätskär granite or to the Rysskär granite " (*ibid.*, p. 127) ; " granitization at the time of Hangö granite " (*Migmatites* II, 1926, pp. 34, 69) ; " granitization processes which are connected with the eruption of these different granites " (*ibid.*, p. 36).

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[1] I refer to these three memoirs as *Migmatites* I, II, III, from now on.

Enquiry as to what this granitisation was, shows, I think, that it comprised all processes of mixing which gave rise to the rocks that Sederholm styled migmatites. For example, he describes " a number of typical instances of granitization caused by these granites, beginning with those in which the two constituents are better separated and ending with the more completely mixed rocks " (*Migmatites* I, 1923, pp. 101-2) ; the typical instances given include veining, lit-par-lit striping, solution during veining, development of patches of granite in the country-rocks, the formation of eruptive breccias or agmatites, and the endomorphism of the granitic magma itself (*ibid*., pp. 102-110). Again (*ibid*., p. 128) the formation of eruptive breccias is called a "stage of granitization " ; further (*Migmatites* II, 1926, p. 55) an example of granitisation is provided by an injection " by aplitic veins which very intimately permeated the older rocks, so as *to change . . . them to migmatites* " (my italics). It appears to me to be clear that granitisation and migmatisation were more or less equivalent to Sederholm. We may examine migmatisation a little closer.

In his preliminary memoir, *Om Granit och Gneis*, 1907, p. 110, Sederholm had defined migmatite as follows :

> " For the gneisses here in question, characteristic of which are two elements of different genetic value, one, a schistose sediment or foliated eruptive, the other, either formed by the resolution of material like the first or by injection from without, the author proposes the name of *migmatites :* the position of this rock group being intermediate between eruptive rocks, proper, and crystalline schists of sedimentary or of eruptive origin."

Twenty years later Sederholm again defined migmatite :

> " The present writer thinks it necessary to use a designation for these hybrid rocks which really characterizes their appearance and origin. They look like mixed rocks, and they originated by the mixture of older rocks and a later erupted granitic magma, and therefore the name *migmatite* is the most appropriate " (*Migmatites* II, 1926, p. 136).

The eruptive components of migmatites " may belong to different granites, sometimes to two or even more of them " (*ibid*., p. 136). " With the more complete assimilation of the older rocks, it will in some cases be rather difficult to determine the original character of the older components, e.g., to discriminate between granitized gneissose granites and very strongly granitized leptites " (*ibid*., p. 136). Migmatites are, to Sederholm, always connected with granites.

I select certain aspects of these remarks of Sederholm's for discussion. The first concerns his requirements that migmatites should " look like mixed rocks." This is a matter that I touched upon in a preliminary fashion in my Address of last year (*loc. cit*., p. 75), where I recalled that Niggli also had included this clause in his definition of migmatite (P. Niggli, *loc. cit*., 1942, p. 36). Likewise for K. H. Scheumann (*Tscher. Min. Petr. Mitt*. 48, 1936, p. 297), who has dealt with the nomenclature of migmatites, a coarsely mixed structure is necessary in these rocks ; this structure arises by the heterogeneous mixture of older solid rocks and younger melt solutions of different origins. This insistence on a coarsely mixed structure appears to me to give rise to considerable difficulties in any rigid application. It will be recalled that the products of imbibition, permeation, superposition and similar processes were familiar to the French in many granite-contacts ; such products were in most cases by no means coarsely mixed. Further, Sederholm has described similar operations and similar products in the Finnish complexes. For example, in the 1907 *Om Granit och Gneis*, we find figured and described a migmatite in which " the whole rock is penetrated by a network of veins, in which the material is more massive than in the other parts, although not sharply defined from them " (*op. cit*., p. 97 ; Fig. 1, Plate IV.). That the country-rocks are permeable is shown by the granitisation of quartzite and the contact phenomena around the Rapakivi granites, for example (e.g., " Über die Entstehung der migmatitischer Gesteine," *Geol.*

Rundschau, vol. IV, 1913, pp. 176-7 ; *Migmatites* I, 1923, p. 88). Thus the magma or its juice is able to penetrate and permeate the country-rocks (*ibid.*, 1923, p. 91, *Migmatites* III, 1934, pp. 36, 41, 44, 52). The Hangö granite penetrates the country-rock "intimately so that no boundaries are visible" and has "soaked through the older rock masses, penetrating them *à tâche d'huile*" (*Migmatites* II, 1926, p. 69). If "no boundaries are visible" it appears to me to be unlikely that "coarse mixing" will be discernible. I have seen in Finland masses of homogeneous rock which Sederholm himself demonstrated as migmatites. Anyone who has worked in migmatite areas will admit that the products of imbibition soaking or permeation are usually medium- grained and homogeneous. Are these undoubted results of mixing to be excluded from the migmatites, the mixed rocks ? It seems to me that no useful purpose can be served by retaining this restriction. It is, after all, a question of scale and anyone who takes too much thought of scales should reread his *Gulliver's Travels*. Let us then agree that migmatites need not be *coarsely* mixed rocks.

A second aspect of Sederholm's definition, and one also on which I touched last year, concerns the necessity of a granitic magma being one parent (or perhaps a grandparent) in migmatisation : "even if a part of the veins may be derived from older material which has been dissolved, this dissolution has . . . taken place in connection with the protrusion of a granitic magma" (*Migmatites* II, 1926, p. 136). This is, as we have seen, the position of Michel-Lévy and Lacroix. A new magma which might become available for migmatisation through this "dissolution" is the palingenetic or newborn magma of Sederholm and the process by which such palingenetic magma is made from solid rocks is anatexis. Before I carry this discussion further, I must state that I have never felt the necessity for *both* of Sederholm's terms, palingenesis and anatexis. In many cases, Sederholm used them as interchangeable and I suggest that the term palingenesis should be dropped, since anatexis is able to do all its duties. We may now look into this process of anatexis ; we shall find some unexpected nebulosities.

In his preliminary investigation of the Finnish migmatites as given in his 1907 *Om Granit och Gneis*, Sederholm suggests that in the coast region of South Finland "the phenomena of refusion or re-solution have occurred so extensively that it must be assumed that the whole area has been in a melting condition" (*op. cit.*, p. 101). This substantial fusion, or re-solution, is brought about by the action of magma which, set in motion by processes resulting from the earth's cooling, eats its way to higher levels in the crust. "With increased height, the dissolving and metamorphising power of the magma gradually diminishes" (p. 102). Sederholm continues : "This process of regional resolution . . . or *anatexis* . . . of the solid rocks, does not materially alter the composition of the magma, taken as a whole, because it must assimilate almost *all* the material resulting from the destruction of the magmatic rocks, whose original composition is thus restored" (p. 102). Following Hutton, Sederholm sees :

> "The process of the destruction and gradual renewal of the solid part of the earths' crust as a *circulation*. The granitic magma, once solidified and, in part, decomposed, undergoes again, when brought into the deeper parts of the earth, a resurrection, or . . . *palingenesis*. The regional metamorphism is caused by a weaker form of the plutonic forces, which at greater depth manifest themselves as regional re-solution or anatexis" (*op. cit.*, p. 102).

Admittedly, I am abstracting from the short English summary of a long Swedish paper—and that a preliminary paper—but, even so, I find it very difficult to decide how far a magma is concerned in anatexis and what is its status if one is concerned. But let us pass on to consider a further statement of Sederholm's which appeared in 1913 ("Über die Entstehung der migmatitischen Gesteine," *Geol. Rund.*, vol. IV, 1913, p. 175). In this general paper on migmatites, he remarks that anatexis is due to higher processes than those of metamorphism ; anatexis is, in fact, ultra-metamorphic ; it includes all those processes by which migmatites are formed, together with those characterised by an amalgamation or quickening between rock already solid and a later intruded magma. This statement suggests to me that anatexis and migmatisation were in 1913 not very different matters. The same idea arises from the consideration of Sederholm's account of an eruptive breccia formed by blocks of basic rock in a cement of granite which is given in his first memoir on migmatisation ten years later (*Migmatites* I, 1923, p. 125). After describing the results of the intimate penetration of granitic magma into the basic fragments, Sederholm says : " When the anatexis has gone further, the nebulitic migmatite often looks like a granite or granodiorite containing Schlieren of a more basic material " (*op. cit.*, p. 125). Later he remarks : " When anatexis has proceeded far, the granitised basic rock has often acquired a granitic texture even if it was originally a metabasalt " (*op. cit.*, p. 126). It appears to me from Sederholm's own description of these processes that no production of new magma by refusion need have occurred. Whatever uncertainties we may detect in Sederholm's usage of it, we must admit that there is need for this term anatexis provided it is properly and simply defined. For my part, as I said last year, I take *anatexis to mean the process of forming new magma from solid rocks.* We examined proposals concerning this process last year and we can continue that examination now with special reference to the Fennoskandians.

We may see a not unexpected evolution in Sederholm's ideas during his life-study of the migmatites. At times he was impressed by the great depths in the crust to which (in his opinion) the Finnish Pre-Cambrian rocks had been depressed. The regional refusion in South Finland resulted when " the whole area . . . . was once sunk to so great a depth, that it approached the bottomless magmaocean or tectosphere of the earth " (*Om Granit och Gneis*," 1907, p. 101). In his Huttonian circulation, as we have noted, he envisages a resurrection of magma when denudation products are brought " into the deeper parts of the earth " (*op. cit.*, p. 102). The mountain-making processes, the metamorphism and the protrusion of the great granitic masses are only different phases of the same plutonic activity (*op. cit.*, p. 109). By 1926, however, he emphasised the importance in anatexis and migmatisation of metasomatism or ultrametasomatism brought about by granitic juices—his *ichors*. For example, concerning the migmatites of the Barosundsfjard area, the following statements which I recommend for your careful consideration are made :

> " . . . "These bedded rocks have been . . , intimately mixed up with granite, or granitic juices, transforming them metasomatically into granite-like rock " (*Migmatites* II, p. 25.)
>
> " In the migmatites of Bagaskär and Lövgrund we were able to study the change of the lighter portions of the bedded leptites, by metasomatic changes caused by the eruption of the oldest granite, into rocks of a more and more granitic character . . . . a process which may be described as palingenesis" (*op. cit.*, 27).
>
> " There is in these rocks no marked limit between what could be called metasomatic ultrametamorphism, and the injection of granitic magma " (*op. cit*, p. 28).
>
> ". . . a leptitic schist has been ultrametasomatically . . . changed to such a degree as to reach the stage of refusion " (*op. cit.* p. 29).
>
> " . . . the granitic juices penetrate certain layers and gradually change them metasomatically into rocks with a more or less typical aplitic composition " (*op. cit.*, p.29).
>
> " The ' juices ' of the younger granite permeated the older one . . . and later it changes them ' ultrametasomatically ' into a new granite which in the final stages was able to react on other rocks like an eruptive (*op. cit.*, p. 50).

Sederholm goes on to state that his opinions " have developed in such a direction that he is inclined to ascribe more and more importance to the granitic exudations or ' granitic juices,' or what has been designated by French geologists as *les minéralisateurs*, an expression which has, however, not exactly the same meaning " (*op. cit.*, p. 87). Sederholm is not attracted by this word juice (as having a vegetable flavour about it) and, after careful consideration, decides to use the word ichor instead. Ichor is derived from a Greek word meaning blood of the gods, but also serum or pus, and personally, I prefer using the sweeter juice rather than Sederholm's possibly pathological ichor. The granitic ichors, then, are exudations—" things showing gradations between an aqueous solution and a very diluted magma, eventually also a magma containing much water in a gaseous state " (*op. cit*., p. 89). They do not cover the gaseous matter involved in typical pneumatolysis (*op. cit*., p. 89).

Sederholm agrees with the French that great quantities of solvents are necessary for metamorphism ; " these solvents are in general exudations from eruptive masses, either visible or hidden at great depth " (*op. cit*., p. 129). Ichors are active also in autometamorphism and in the promotion of deuteric changes ; " occasionally, even a complete recrystallisation of an already solid granite may take place when it is soaked in its own ichor " (*op. cit*., pp. 133-4). Soaking of the country-rocks by granitic magma and especially by granitic ichor is re-affirmed by Sederholm ; " the granitic magma often advanced à tâche d'huile " (*op. cit*., p. 134). This soaking may lead to the formation of new magma ; " the ichor of the granite has been able intimately to penetrate the older rocks giving them a new, ' palingene,' eruptivity, even in cases where their chemical composition has remained unchanged. In most cases, however, they have been gradually changed, when soaked with the granitic magma, or its ichor, and their composition has more and more approached that of the new granite " (*op. cit*., pp. 134-5). This intimate penetration by the ichors, combined with the mechanical injection of the older rocks, gives rise to the immense variety of the migmatites. Though these processes might be described as ultrametamorphic, since they clearly surpass in strength ordinary metamorphic processes, they are really essentially different from these because they lead to " the formation of rocks which are no more crystalline schists, but in which at least one of the components behaves as an eruptive " (*op. cit*., p. 135). Instead of ultrametamorphism, then, Sederholm " prefers the name anatexis which corresponds to refusion although in some cases re-solution would be more appropriate " (*op. cit*., p. 135). This " anatexis of the crustal granitic masses has been caused mainly by the influence of emanations from the abyssal magma . . . ." (*op. cit*., p. 135).

In the foregoing pages I have given a number of quotations from Sederholm's writings which I believe are a fair sample. I have made at various times a fairly detailed examination of his works. I have unfortunately, however, never been able to make up my mind as to how rigidly he held to the view that granitic magma was necessary in migmatisation. I consider that I can detect, and that without bias, certain leanings towards the Swedish " lateral secretion " view in spite of the strenuous debates with Holmquist and other Swedes on this very matter. I present the leading points in this Finnish-Swedish discussion in a later page ; now I desire to comment upon the general aspects of Sederholm's work of interest to us on this present occasion. He had dissected, not only petrogenetically but also stratigraphically, the immense complexities of the Finnish Pre-Cambrian. He had demonstrated there an enormous extension of the phenomena made familiar—to those who would listen—by the French school. He had proposed a regional re-fusion of deeply buried portions of the crust—re-fusion connected with granitic magma. In his later studies he stressed the importance of soaking in migmatisation and described the results of processes which in my opinion come within my restricted definition of granitisation. At this stage of his work, too, he emphasised the importance of metasomatism in migmatisation. It is not ungenerous to suggest that he had been influenced in his later developments by the 1921 work of V. M. Goldschmidt on injection-metamorphism in the Stavanger district of Norway, work in which metasomatism found a prominent place. We may examine the pertinent points of Goldschmidt's contribution.

Having concluded his classic studies on the contact-metamorphism of the Oslo region, V. M. Goldschmidt proceeded in 1911 to investigate certain problems of regional metamorphism in Southern Norway. Between 1912 and 1921 the results appeared as five parts of his *Geologisch-Petrographische Studien im Hochgebirge des Südlichen Norwegens* (*Videnskapsselskapets Skrifter, I. Mat. naturv. Klasse*; 1912, No. 18; 1912, No. 19; 1915, No. 10; 1916, No. 2; 1920, No. 10). All these are worthy of profound study by the student of metamorphic geology, but it is the fifth part, *Die Injektionsmetamorphose im Stavanger-Gebiete* (*Vidensk. Skr.* 1920, No. 10; 1921) which particularly concerns us at present. Goldschmidt describes in the Stavanger area a kind of contact-metamorphism which is added to the regional metamorphism. The typical rock of regional development is a quartz-muscovite-chlorite-phyllite and this is transformed through intermediate stages marked by the incoming of biotite and garnet into albite-porphyroblast schists and augen-gneisses. These coarse gneisses with large augen of alkali felspar are demonstated to be the result of the "injection-metamorphism" of pelitic rocks during which there has been an influx of silica, soda and lime into the host. Goldschmidt compares his results with those obtained in other granite-contacts, especially the French. Of particular interest to us now, however, is his discussion of metasomatic processes which take place in silicate rocks (*op. cit.*, pp. 132-7); Goldschmidt elaborated this discussion in a separate communication ("On the Metasomatic Processes in Silicate Rocks," *Econ. Geol.*, vol. 17, 1922, p. 105). Metasomatism changes the composition of metamorphic rocks through the agency of imported substances—gases, aqueous solutions or melts. One of the most important branches of this metasomatism is that brought about by alkali-transfer; during this alkali-metasomatism, the alkalies may be exchanged as in the formation of myrmekite, or they may be fixed by the excess alumina in the original rock as in the formation of felspar in injection-complexes and illustrated at Stavanger, or they may be fixed by ferromagnesian minerals or by quartz (*op. cit.*, 1922, p.110). I have introduced Goldschmidt's work at this place in order to record the foundations on which much of the later proposals has been based.

I have already mentioned the debate between Sederholm and Holmquist on the origin of the "veins" in the "veined gneisses," and I propose to look into this in a little detail. We may recall Sederholm's position; the veined gneisses are "formed by injection of granitic veins" (*Om Granit och Gneis*, 1907, p. 95) and "the aplitization of older rock masses which plays such an important role in the formation of the veined gneisses, can in no case be explained, in the present region, as due to an ultrametamorphism independent of the eruption of granites, every aplite or granitic vein (being) genetically connected with some special granite . . ." (*Migmatites* I, p. 150). Persuing his pathological bent, Sederholm calls the veined gneisses *arterites*—the rocks have become filled with new blood. In an arterite or arteritic migmatite "a schistose rock has been subdivided especially along the planes of foliation" (*Migmatites* II, p. 136). The arterites result from fine injections into pre-existing rocks and Sederholm "cannot therefore share the opinion of Holmquist, according to whom many of the veined rocks . . . . should be regarded as *venites*, i.e., as rocks where the veins should be mainly exudates from the surrounding rocks" (*Migmatites* II, p. 137).

The Swedish view has been put forward especially by P. J. Holmquist ("Typen und Nomenklatur der Adergesteine," *Geol. Fören. Förh.*, vol. 43, 1921, p. 612; "Om Pegmatitpalingenes och Ptygmatisk Veckning," *ibid.*, vol. 42, 1920, English Summary, p. 209). Holmquist held that the veins of the veined gneisses were unrelated to granitic intrusion, but were the result of the inner deformation of rocks during regional metamorphism. He admits a local granitic veining, but the veined gneisses are so widespread and their structure is so fine and regular than an origin by injection is excluded (*loc. cit.*, 1921, pp. 612-3) ; the presence of an igneous body simply intensifies the process of veining (p. 615). In high-grade metamorphic zones, there thus arises under suitable conditions a "real fusion of the most fusible rock masses" (*loc. cit.*, 1920, p. 210), a pegmatite-palingenesis, not related to igneous intrusion—the veined gneisses resulted from this *ultrametamorphism*. Holmquist proposed the term *venite* for the veined gneisses, this term having no genetic significance ; there are lateral-secretion venites such as those formed during ultrametamorphism, and there are injection-venites which correspond to Sederholm's arterites.

To the onlooker, much of the debate between Holmquist and Sederholm seems rather academic. Holmquist (*loc. cit.*, 1921, pp. 627-8) considered that in the areas where folding and magmatic injection are coeval, the conditions for a pegmatite vein formation are ideal—high pressure, high temperature and abundance of mineralisers. Changes of a diagenetic, metasomatic, pneumatolytic, palingenetic or magmatic nature are the consequences (*loc. cit.*, 1921, pp. 630-1). Holmquist admits that granitic magmas may develop from the formation of venites whilst Sederholm admits an anatexis especially at great depths. As Sederholm (*Migmatites* II, p. 137) has himself remarked "the difference in principle is not very great between these conceptions." He "thinks that the granitic masses, which have been mobilised already at a very great depth, and their emanations, invade the solid rock masses rising from below, when their van-guard of pegmatitic veins may advance even long before the great army, in some cases joining with revolutionary forces of the country invaded. To Holmquist, the granitic veins of the mixed rocks are in large measure due to the action of such revolutionists, acting alone, on their own initiative, and often having little direct connection with the invaders" (*Migmatites* II, p. 138). It is important to realise, however, that Holmquist's study of the veined gneisses was an important contribution to what we now call metamorphic diffusion and metamorphic differentiation and also to the idea of selective refusion—all these are notions which have been developed by later Fennoskandians such as Eskola, Wegmann and Backlund.

Certain parts of the ground in South-West Finland made famous by the researches of Sederholm have been worked over again on modern tectonic and petrological lines by C. E. Wegmann and E. H. Kranck. Such of the results of these workers as have reference to granitisation in its broadest sense may be noted here ; they are extracted chiefly from the 1931 memoir, "Beiträge zür Kenntnis der Svecofenniden in Finland, I, II," *Bull. Com. Géol. Finlande*, No. 89, 1931. Wegmann concludes that the greater part of the Hangö granite was not a molten silicate mass in the usual sense of the word, but a mass soaked with granitic solutions coming from below. Where this soaked mass moved and met with enough resistance at the walls it presents to us the characters of an *intrusion* ; movement gives an intrusion, no movement gives an area of granitisation. The pegmatite dykes are that part of the granitising solutions which crystallises in joints and opened spaces arising in the permeated mass (*loc. cit.*, 1931, pp. 58-9). Around the "colonnes filtrantes" lies a mantle with different kinds of enrichment in different parts ; in the inner parts is an enrichment of Si and K, yielding a quartz-felspar enrichment, in the outer is an enrichment in Mg in a cordierite-rich zone, whilst still further outside is an epidotised zone of unakites (*loc. cit.*, p. 62). Since material is brought in at one place it must disappear at another place, and a whole series of chemical readjustments are set in motion. The solutions strive in the direction of the gradient of chemical concentration, but they are hindered by the small permeability, the fall in temperature and the formation of insoluble combinations in rocks capable of absorbing the necessary contributions (*loc. cit.*, p. 63). Wegmann relates these events to orogenic movement, this style of movement and atomic movement going hand in hand (*loc. cit.*, p. 64).

Wegmann is a tectonician, trained in the school of Argand. His kinetic schemes are translated into petrological processes by Kranck who considers that in the case of the Hangö granite, solutions permeated along movement-planes and spread out from these (*loc. cit.*, pp. 92-3). In the granitisation zone typical minerals are cordierite and anthophyllite, farther out are lower temperature minerals like andalusite, kyanite and garnet, whilst at still lower temperatures appear staurolite and finally tourmaline. The whole process is one of exchange of minerals rich in MgFe(Ca) against KAlSi ; a magnesia metasomatism, associated with the formation of a potash-granite (*loc. cit.*, p. 94). Kranck concludes that migmatisation is not the result of a melting due to granite intrusion but arises through a metasomatism brought about by pegmatitic solutions, the ichors of Sederholm ; granitisation is a metasomatism rather than a migmatitic intrusion (*loc. cit.*, p. 96). In later studies Kranck reaffirms this conclusion that granitisation is not an injection of granitic magmas, but an injection of gases or watery solutions which lead to a pure metasomatism whereby transport of material goes on without marked mechanical alteration in the rock affected (e.g., " Über Intrusion und Tektonik im Kustengebiete zwischen Helsingfors und Porkola," *C.R. Géol. Soc. Finl.*, No. X, 1937, p. 85). The position of Sederholm, especially so far as the presence of a granitic magma is necessary for migmatisation is concerned, is becoming undermined by operations in his own citadel.

After these detailed studies in Finland and associated with some spectacular work in Greenland, which I note later, Wegmann was moved to discuss general problems of the migmatites. The relevant papers are these : " Zur Deutung der Migmatite," *Geol. Rund.*, vol. xxvi, 1935, p. 305 ; " Über einige Fragen der Tiefentektonik," *ibid.*, p. 449 ; " Geologische Merkmale der Unterkruste," *ibid.*, vol. xxvii, 1936, p. 43. According to Wegmann, the occurrence of migmatites is of two types, one in the marginal zone of granites which have been intruded as magma, and the other in a zone where the country-rocks have been transformed into granitic rocks. Since all sorts of sedimentation-textures and tectonic structures are preserved in granite, it follows that the migmatisation has passed like a wave through the country-rocks leaving a granitic and gneiss zone behind as a witness of its passage (" Zur Deutung der Migmatite " *loc. cit.*, pp. 311, 312). The advance of this migmatisation front combined with the not coincident advance of the cooling-front leads to the immense variety of phenomena in migmatites (*loc. cit.*, p. 315). Wegmann defines and discusses four terms constantly employed in the study of migmatites ; we may deal with these terms at some length.

i. INTRUSION. The entrance of magma (Schmelzflüss) into spaces which it opens.

ii. INJECTION. The spurting-in of solutions, pneumatolytic or hydrothermal in character. The use of the term injection-gneiss for migmatites in general is not warranted—injection must be proved.

iii. MELTING-UP (Aufschmelzung). The country-rock becomes a structureless melt which crystallises anew. This process is not important in migmatisation (*op. cit.*, p. 318).

iv. MIGRATION OF MATERIAL (Stoffwanderung)—often called metasomatism, permeation or imbibition. The migrating material moves as molecules or atoms through the rock, and reacts with its host in a process usually called metasomatism (*loc. cit.*, p. 319). The migration proceeds by the oil-spot mechanism, no channels being visible (*loc. cit.*, p. 321). Pseudomorphs of the country-rock are formed with preservation of its geometry : there has thus been no increase in volume, so that material has moved out also. If the structures and textures of the country-rocks are preserved there can be no question of melting-up (p. 322) ; in fact, melting and melting products are most undesirable terms in migmatisation and solution and solution products are preferable (p. 323). Wegmann emphasises the importance of the intergranular film in the movement of material and associated reactions. By integration of the multitude of concentration gradients around the individual grains, there is produced a kind of front in which most changes take place. When the material in the host available for reaction is used up, the front, if the temperature is favourable, moves on. Thus, the relation between supply and cooling decides where the margin of, say, granitisation shall be. If the front is stationary there may be a sharp contact which, however, does not mean intrusive contact ; as is well known, intrusions can have hazy contacts. Fronts may be characterised by different minerals, as for example soda at Stavanger, potash at Hangö, magnesia at Orijarvi (*loc. cit.*, pp. 326-7). As one front advances it may cause the advance of another ; for example, the formation of a potash or soda front as witnessed by felspathisation may push out the unwanted magnesia and give rise to a cordierite front (*loc. cit.*, p. 327). The temperature gradient has a profound influence on the movement of the migmatite front. An increase of temperature increases the movement of the intergranular film, and more movement of material brings in more heat ; further, many of the reactions go on with evolution of heat ; all these add up (pp. 328-9).

So far Wegmann had concerned himself with movements of the immigrant materials and he next considers movements in the substratum and the migmatite zone. A distinction must be drawn, he maintains, between happenings in the non-migmatitic superstructure (Oberbau) and the migmatitic infrastructure (Unterbau) lying below (*loc. cit.*, p. 332). The two zones fold in disharmonic fashion, and the migmatite zone comes to fill the arches in the superstructure, as is seen in Greenland. Between the two zones is a transitional zone which is the site of the so-called regional metamorphism and may be narrow as at Pellinge in Finland or wide as in the Scandinavian Caledonids. During the pressing forward of the migmatite front, the wave of ' regional metamorphism ' of the transitional zone moves forward in sympathy. In fold-belts with great cross-shortening, the superstructure is the site of over-thrusts, the transitional zone of great nappes and the infrastructure of steep flowage folds. Further, since both the upper part of the infrastructure and the transitional zone were both once in the superstructure, it is not unexpected that relics of superstructural characters are found in them (*loc. cit.*, p. 334). The folding of the superstructure is of two kinds, by contraction of the segment or by collection of the infrastructure into arches and its heaving-up. In these compressed arches of the infrastructure, recrystallisation is especially intensive ; in many cases obvious granite stocks break through the folded gneisses ; when these stocks are investigated in detail, however, many of them prove to be the recrystallised developments of strongly folded migmatites (*loc. cit.*, p. 334). By strong folding of the superstructure tongues of infrastructural type are formed, and extreme kneading of such tongues and their recrystallisation convert them into granitic intrusions in some of which a migmatitic origin is no longer discernible. These tongues of infrastructural nature can form at different phases ; when they are overhauled by the migmatite front they are the Early Granites ; when they are developed at the maximum of the migmatisation and invade the transitional zone they are the Main Granites ; when they are formed during the retreat stage of the fronts, they intrude the already solidified part of the migmatite zone and are the Late Granites (*loc. cit.*, p. 335).

The migmatite front is considered by Wegmann to encroach from below on to the base of the superstructure ; heat and material flow in and create an infrastructural condition whereby geosynclinal sediments become the host-rocks for fresh migmatitic cycles (*loc. cit.*, p. 336). When the temperature and pressure reach certain limits the rocks of the crystalline cores become capable of movement, their contacts begin to move, transport of material by the intergranular film takes place and new migmatites arise in the old basements (*loc. cit.*, p. 338). As the migmatite front advances higher in the sedimentary pile, it cuts across the stratigraphical boundaries, and may develop an arch-like form ; the transitional zones, which are the zones of regional metamorphism, thus lie obliquely to the stratigraphical planes (*loc. cit.*, pp. 339-40).

As just noted, Wegmann considers that granitisation has forward optimum and backward stages in all of which migmatites press forward into the outer zones and solidify there as granites, early, main, or late. Relations of these granites to the country-rocks differ and depend upon the zone of their intrusion. Investigation in many migmatite areas shows that many granites and granodiorites are of mixed origin ; they display relict structures which cannot be accounted for by derivation for a basaltic magma (*loc. cit.*, pp. 342-3). Wegmann (*loc. cit.*, pp. 343-4) holds that according to the original concept migmatites are magmas ; this is a matter I discussed at some length in last year's Address and I need not persue it further here beyond recalling that I consider a distinction between magma and migma to be essential for progress in these studies.

The last aspect of Wegmann's general discussion that I wish to notice concerns the source of the invading material. This source is usually supposed to be from associated intrusives. These intrusives admittedly have great contact-zones in the transitional zone, that is in the zone of regional metamorphism, but they do not attain the size of the migmatite areas. Many of these intrusives, moreover, are themselves of mixed origin. It must be confessed that in many regions the source of the invading materials is not yet known. They must come from great depths at which they must occur in quantity. If they arise from deep melts, two possibilities may be entertained : they may be concentrated by a crystallisation-differentiation or they may be squeezed out from the depths (*loc. cit.*, pp. 345-6).

Many of Wegmann's views are illustrated in his Greenland work (e.g. "Caledonian Orogeny in Christian X's Land," *Medd. om Grönl.*, Bd. 103, No. 3, 1935 ; "Geological Investigations in Southern Greenland," *Medd. om Grönl.* Bd. 113, No. 2, 1938), and there is no need to elaborate them still further here. I have given them at some length because I suspect that the acquaintance of British geologists with the Finnish school has often stopped at Sederholm. It is well at least to know where the latest developments are to be found. We shall note further developments in Fennoskandia in the next section of these remarks, but I now wish to make a brief reference to Niggli's criticisms of Wegmann's views. Niggli ("Das Problem der Granitbildung," *Schweiz. Min. Petr. Mitt.* Bd. XXII, 1942, pp. 1-84) contends that Wegmann has enlarged Sederholm's concept of migmatite by admitting many granitisation processes in which magma has played no part (*loc. cit.*, pp. 27-8). Further, Wegmann's molecular transfer leads to the formation of uniform rocks in which host and transferred material are not separable—such rocks do not comply with Sederholm's rule that migmatites "look like mixed rocks" (*loc. cit.*, p. 29). The intergranular film of Wegmann (which Niggli claims as his own invention in *Die Gesteinsmetamorphose*, 1924, pp. 159, 162) really amounts to very little in metamorphism and if one follows Wegmann the whole way then one has to accept practically all metamorphic rocks as migmatites (*loc. cit.*. pp. 29-30). Wegmann is never very clear, according to Niggli, as to whether he is dealing with a granite solidified from a magma or a recrystallised country-rock nor as to how much solution phase is present at any moment nor as to how much is required for activation or mobilisation of the material. In the ordinary processes of metamorphism, Niggli protests, an inhomogeneity can be produced by the plasticity of some parts and the rigidity of others, so that, as in the granite-gneiss of the

Pennids, the result should be a "migmatite" (*loc. cit.*, pp. 35-6). This leads Niggli to define the term migmatite and I requote his definition :

> "Migmatite should be restricted to rocks and rock-zones which show coarsely variable magmatic and metamorphic structural patterns, originate in the transitional zone between the magmatic and the solid state, and have undergone a metamorphism during which, without any increase of volume, a considerable part attained a fluidal or melted condition. The association of migmatites with a granitic magma is not necessary to the definition nor do the source and history of the fluid phases affect this either. Mixed rocks like Holmquist's venites can thus be accepted. It must expressly be emphasised that rocks with a comparable appearance may be formed which cannot be called migmatites because they did not originate in the border-region liquid : solid within the earth considered as a whole" (*loc. cit.*, pp. 36-7).

Niggli objects, and rightly in my opinion, to Wegmann's treatment of magma and maintains that Wegmann uses magma when migma would be more acceptable (*loc. cit.*, pp. 39-40). Niggli finally restates the magmatist position, and this statement, in my free translation, is worth giving here :

> "In summary, we can well say that granite and granodiorite with the usual chemical, mineralogical, structural and textural characteristics have the typical characters of magmatic rocks and that their explanation as normal metamorphic rocks, for example as metasomatically altered sediments, *appears impossible to all petrographers who have investigated a great deal of eruptive and metamorphic rocks in the field and in the laboratory*. The new idea that granite is a metamorphic rock rests on no kind of fundamental investigation. True migmatites are marginal to granite as Sederholm, Grubenmann, Niggli, Holmquist, Barth, Scheumann readily agree. So-called "granitised" metamorphic rocks must be separated from the granites and granodiorites."

I regret in no way that I have been so undignified as to italicise a revealing portion of Niggli's statement above. Both Niggli and Wegmann are Swiss ; perhaps in their haven of neutrality, they will favour us with further skirmishes.

Another Fennoskandian, Helge Backlund, writing about the same time as Wegmann, put forward somewhat similar notions which he has since developed. According to Backlund ("Der 'Magmaaufsteig' in Faltengebirgen," *C.R. Soc. Géol. Finlande*, No. IX, *Bull. Com. Géol. Finl.*, No. 115, 1936, pp. 293-347) the crystalline rocks, including in these the plutonites and the metamorphites, mark stages in the evolution of the geosynclines—a fact not generally recognised because, firstly, crystalline rocks are not important in the Alps and second, crystalline rocks are regarded as having been formed at great depths. Backlund believes that this relative depth must be small in comparison with the depth of folding and the total thickness of sediments in the geosyncline (*loc. cit.*, pp. 293-4). Sederholm, as we have already seen, held that the older the mountain belt was, the deeper erosion had bitten into it. Backlund shows that Aktualismus is valid in the oldest fold-belts, and that fold-mountains of all ages are capable of being compared. The series of ultrametamorphic stages or stages of increasing mobility, venite —> augengneiss —> arterite —> migmatite —> palingenite —> diapirite, brought about by the increased activity of a probably alkali-silicate solution (ichor) and an increase in temperature and considered typical of the old fold-chain, is now known from fold-belts of all ages. The changes take place in response to the rise of the migmatite front (*loc. cit.*, pp. 294-6). Admittedly very irregular arrangements are found in the old fold-belts, but it must be remembered that in these no great vertical thickness is visible, whilst in the younger fold-belts no great area of crystallines is exposed (*loc. cit.*, p. 302).

Backlund agrees with Wegmann that in the latter's transitional zone or zone of regional metamorphism, metamorphic zones of the customary type will be recognisable, but in the migmatite front such become lost, distinctions between 'para' and 'ortho' rocks disappear, and the boundary between ultrametamorphic and plutonic rocks gradually vanishes. As the migmatite front advances, different rocks react in different ways. The migmatisation of pelitic sediments is a familiar occurrence ; only a small influx of soda and silica is needed to change the chemical composition of a clay into that of a granite ; clay rocks are widespread homogeneous rocks fit for large scale migmatisation and granitisation. But in the geosynclinal piles, quartzites and limestones are likewise abundant, but yet are rare in the migmatite areas. What has happened to those monomineralic sediments ? (*loc. cit.*, pp. 309-11). After a detailed examination (*loc. cit.*, pp. 311-340) of various occurrences of quartzites and limestones in migmatite areas in Fennoskandia and Greenland, Backlund concludes that they have been transformed into granite and granodiorite respectively by some kind of diffusion process in which KNaAlSi play the chief part (*loc. cit.*, p. 342-3). Migmatites are never homogeneous melts, but a mixture of strongly preponderant solid phases with a little fluid phase, or pore-magma, to use Eskola's term (*loc. cit.*, p. 321). What we call ' rise of magma ' is the same thing as the rise of the migmatite front. Elements with small atomic radii, such as Al and Si, form the spearhead of the attack, the alkalies, expecially K, follow later ; Early Granites are accordingly poor in alkalies, Late Granites are rich in potash. This ' rise of magma ' is granitisation. During it, the volume-changes of the different types of sediments form a series increasing from pelite through quartzite to limestone. Because of this, original pelites on migmatisation remain closest to their original position as paragneisses, whilst derivatives from the quartzites and limestones become orthogneisses, move into the higher parts of the fold-mountains and, at still higher levels, intrude as true magmatic rocks (*loc. cit.*, p. 343).

Thus, for Backlund, all the so-called magmatic rocks (except the original basalts and their direct differentiates) are developed from geosynclinal sediments by granitisation ; these products may arise in situ and then become plutonites, or they may come up from below to give the diapirites, piercing through the original cover (" Die Umgrenzung der Svekofenniden," *Bull. Geol. Inst. Upsala*, vol. xxvii, 1937, p. 239). These views of Backlund, as may be expected, caused, and still cause, a considerable amount of criticism among other Scandinavian workers ; his major debate with Von Eckermann forms the subject of the next section of this Address ; but I wish to refer first to his general statement (" Zur ' Granitisationstheorie,' " *Geol. Fören. Förhandl.*, vol. 60, 1938, pp. 177-200) of the granitisation theory, which he issued in reply to his critics, especially N. H. Magnusson (" Die Granitisationstheorie und deren Anwendung für Svionische Granite und Gneise Mittelschwedens," *Geol. Fören. Förhandl*, vol. 59, 1937, pp. 525-548). He considered that granitisation includes such processes as migmatisation (*loc. cit.*, p. 179) and anatexis (*loc. cit.*, p. 181) and now applies it to the formation of the older Finnish granites, though originally Sederholm only demonstrated its occurrence in association with the emplacement of the younger Pre-Cambrian granites of that area. Among the evidence described are the presence of relict sedimentation- and folding-structures in these granites, the regional orientation of series of xenoliths, and their relations to dyke-intrusions. It is true, says Backlund, that such younger granites as the Hangö granite are accompanied by great developments of pegmatite (and thus Sederholm's concept of the ichor or granitic juice is understandable), whereas the older granites lack pegmatites. This is explicable if the granitising material, the emanations, though probably of the same composition, met different kinds of country-rocks. In the case of the older granites the country-rocks were poor in alkalies and so completely used up the permeating alkali-rich fluids ; but when the younger granites were formed the country-rocks had already been felspathised so that there was an excess of ichor which appears as pegmatites. Ichors, in Backlund's opinion, cannot however be identified with pegmatite (*loc. cit.*, pp. 181-2).

Turning to the great Scandinavian granites, shown on the maps by continuous areas of uniform colours, Backlund remarks (*loc. cit.*, pp. 186-7) that these ' granite ' masses are in reality very heterogeneous, depending upon the heterogeneity of the sediments which have been granitised. He rightly insists on the importance of the room-question in the interpretation of the older Pre-Cambrian. The rocks are usually folded and compressed ; emplacement of granite in such a milieu can only be replacement ; for a reasonable answer to this room-question " scheint ein Granitisationsakt der einzigen Weg zur Lösung zu gewähren " (*loc. cit.*, p. 187-9).

According to Backlund, as we have seen, granitisation in situ (i.e., granitisation in my sense) causes an increase in the amount of material in a given space ; the result is that a *mobilisation* or rheomorphism[1] of the granitisation products takes place. This mobilisation leads to flow-movements, differential movement, flow-folds, penetration and intrusion in the direction of least resistance (*loc. cit.*, p. 190). Granitisation is controlled by the capacity of the country-rocks to allow diffusion both as regards quality and quantity of material. Diffusion will increase with temperature and will depend also upon textures, such as schistosity, and upon the make-up of the sediment. Granitisation thus may become the culmination of metasomatism and find its expression in rheomorphism leading to sharp contacts (*loc. cit.*, pp. 191-2). Backlund prefers *emanation* as a neutral term to ichor and granitic juice, which denote more or less directly residuals from the crystallisation of a granitic magma, since in many cases granitisation has clearly been caused by contributions which are not in the least related in any character to such residuals (*loc. cit.*, pp. 195-6). Finally, he emphasises the selective nature of the action of the emanations (*loc. cit.*, p. 196).

We saw in an earlier page how the French school came to fruition in the work of Michel-Lévy and Lacroix ; we have now seen how the work of the Fennoskandians, Sederholm, Holmquist and others, has flowered in that of Wegmann, Kranck and Backlund, though it is perhaps true that many of the later blossoms would have appeared exotic and some even monstrous to their early planters. Let us get a broad view of these latest Fennoskandian developments as they will undoubtedly influence the future course of the granitisation theory. Sederholm's requirement of an igneous granitic magma coming from below and acting as one parent in migmatisation has to a great extent been set aside. Granitisation, as I use the term in this Address, has become the most important aspect in migmatisation. It is considered to have been brought about by the metasomatic activities of emanations of no specially defined origin, which have diffused up into higher levels of the crust. Their work is helped by an intergranular film, pore liquid or pore magma, and they are able to transform great masses of sediments into granitic and migmatitic rocks. Under certain circumstances of concentration or of orogeny, the granitised rocks are capable of becoming mobilised, of moving and of acting as intrusive rocks. They can thus rise into higher levels of the crust and lose contact with their genetic associates. The process of granitisation and migmatisation advances in wave fashion and through the rocks ' fronts ' of different qualities move at different speeds with different results ; if anything is brought in, something must move out. The movements of the migmatite front, with the generation of granitic rocks and the impression of regional metamorphism on great masses of rocks are correlated with tectonic events in considerable sectors of the earth's crust.

These latest Fennoskandian results, right or wrong, are immensely stimulating. They cannot be ignored, and if they are not accepted they must be combatted with vigour. I have now one further contribution from Fennoskandia to consider, but it is of sufficient interest to merit a new section of this Address.

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[1] " Der Verfasser schlägt hiermit vor, unter der Bezeichnung ' Rheomorphose ' die gesamten Prozesse der thermalen, partiellen oder gänzlichen Verflüssigung eines praexistierenden Gesteins unter Zuschuss von kleineren oder grosseren Mengen, auf Diffusionswegen zugewanderten neuen Materials zusammenfassen " (Backlund).

V. RAPAKIVI.

At various places in my examination of the Fennoskandian contributions given in the previous section of this Address, I have mentioned that most typically Fennoskandian rock, the rapakivi granite, and have indicated the existence of profound differences of opinion concerning it amongst Finnish and Swedish geologists. I propose now to give some account of this discussion since its prime topic is whether this celebrated rock is a granite in the orthodox sense or a product of granitisation. This account, too, will serve as a fitting preliminary to the examination of felspathisation which follows.

The rapakivi granites (*rapakivi*, Finnish, *crumbly stone*) make very large rounded masses in South Finland, a major one on the east side of Lake Ladoga, a second in the Viborg area to the west of this lake, and a third in the Pori region on the east side of the Gulf of Bothnia ; the Åland Islands are dominantly of rapakivi, and other extensive developments are seen on the west side of the Gulf of Bothnia and elsewhere in Sweden and in Norway. The typical rock, the rapakivi granite proper, is characterised by abundant large ovoids usually about 4 cms. across of potash-felspar which lie in a matrix of quartz, potash-felspar, plagioclase and dark mica, and, sometimes, hornblende ; often the potash-felspar ovoids are mantled by a ring made up of small oligoclases, and it is this striking phenomenon which is usually in mind when the rapakivi granites are considered. It must be mentioned, however, that many of the granitic rocks geologically associated with the rapakivi granites proper do not show these mantled ovoids. Further, although Sederholm ("On the Geology of Fennoskandia, with Special Reference to the Pre-Cambrian," *Bull. Com. Géol. Finlande*, No. 98, 1932, p. 24) held that the rapakivi granites of Fennoskandia were of one general age and quality, it would be stifling the whole discussion as to their origin not to admit the occurrence both in Fennoskandia and elsewhere of granitic rocks, with rapakivi textures, of other ages. The group of rapakivi granites occurs in Fennoskandia in association typically with the Jotnian Sandstone or its equivalent or with some other sandstone ; Backlund. ("The Problems of the Rapakivi Granites," *Journ. Geol.*, vol. xlvi, 1938, p. 347) has said "it has become a rule in Fennoskandia, when encountering a Jotnian sandstone area to search for rapakivi or their effusive equivalents in the neighbourhood."

For most people, of course, the rapakivi granites are igneous rocks, consolidated from a magma ; some petrographers, for example A. Johannsen, admit they are "abnormal granites" and considerable discussion has been concerned with their "abnormalities," expecially those of the felspars. Any reader of this Address who has available Sederholm's memoirs on migmatites will find an account of the rapakivi granite of the Pellinge district, illustrated with excellent plates, in *Migmatites* I, pp. 75-95. As I have been fortunate enough to have seen something of this occurrence, I propose to select from Sederholm's description certain points for remark. A contact of the granite, here with typical ovoids, is well exposed on a small island south-west of Buckholm in Perna and has been described and figured in detail by Sederholm ; the point of interest to us is that ovoids occur in the country-rock, a meta-andesite, for a short distance from the granite. This is not an isolated occurrence and many examples are supplied by Sederholm (e.g., *Migmatites* I, Figs. 28, 39, 40) and others. These phenomena prove, according to Sederholm (*loc. cit.*, p. 88) "that the schistose rock has been permeated by the granitic magma." Again, he holds (*loc. cit.*, p. 88) that "no geologist could visit these localities without being convinced that the granitic magma is able intimately to permeate neighbouring rocks."

Before commenting upon these statements, we may look a little closer into the mantled ovoids of felspar which give the real rapakivi its "abnormal" character. These ovoids are very remarkable bodies indeed. Some are un-mantled and consist of perthitic microcline often with a border zone containing idiomorphic quartz. The mantled ovoids show a polysomatic ring of oligoclase, allotriomorphic against the internal potash-felspar and idiomorphic outside. Occasionally the very cores of these mantled ovoids are composed of groundmass minerals which are surrounded by larger potash-felspars and then comes the plagioclase rim. The potash-felspar ovoids may contain concentric rings of inclusions of all the minerals of the groundmass. Quartz-felspar intergrowths of various kinds are common in association with the ovoids (Backlund, *op. cit.*, pp. 366-8). It is clear, even from this skeleton statement, that if the mantled ovoids have arisen through processes of magmatic crystallisation then these must have been, like Sam Weller's knowledge of London, "extensive and peculiar."

I need give here only an indication of the proposals which have been made by magmatists to interpret these ovoids ; a full discussion of the problem has been presented by Sederholm ("On Orbicular Granites," *Bull. Com. Géol. Finl.* No. 83, 1928, pp. 83-96). We may here with advantage glance at the complexity and variety of these proposals, remembering all the time that rapakivi ovoids occur also in the country-rocks. P. J. Holmquist ("Rapakivistruktur och granitstruktur" *Geol. Förens. Förhandl.*, vol. 23, 1901, pp. 150-161) thought that the ovoid shape resulted from the formation of drops of magma out of which each felspar crystallised—the shelled arrangement was still not explained. According to B. Popoff ("Ueber Rapakivi aus Südrussland," *Trav. Soc. Imp. Nat. St. Pétersbourg*, vol. 31, pp. 256-260) the shelled texture was due to a coating deposited when the orthoclase kernel had sunk into a new environment —repeated sinkings and coatings gave rise to the complex ovoids. Vogt held that the ovoids represent eutectic mixtures of orthoclase and oligoclase, and Harker (*The Natural History of Igneous Rocks*, 1909, pp. 267-8) sees in them the remarkable effects of the supersaturation of the magma with orthoclase and oligoclase alternately. Wahl suggested that the rapakivi crystallisation had taken place in two stages ; the early orthoclase crystals were more or less completely re-fused into drops by reduction in gas-pressure. I admit that I am not competent to follow Wahl's explanation, but I can at least agree with Sederholm (*loc. cit*,. p. 91) that it is "geologically as well as geophysically very complicated." Sederholm himself appeals to a high viscosity in the magma, due to the great amount of oligoclase substance present in it.

The proposals given above refer to Fennoskandian occurrences ; felspars with rapakivi arrangements, however, are found in many granites and the interpretations of these add to the variety. Thus rapakivi felspars occur in the granite of Trégastel, Côtes du Nord, described by Thomas and Campbell Smith ("Xenoliths of Igneous Origin in the Trégastel-Ploumanac'h Granite, Côtes du Nord, France," *Quart. Journ. Geol. Soc.*, vol. lxxxviii, 1932, p. 291) ; these authors state that "there can be no doubt that the cause of the rapakivi structure lies in this basification of the liquid phase of the granite magma existing between the already formed porphyritic crystals of microcline. The available potash would be in a measure diminished by the potential formation of biotite so that on continued crystallization an alkaline plagioclase would form on the nuclei of microcline." Further, A. K. Wells and S. W. Wooldridge ("The Rock Groups of Jersey, with special Reference to the Intrusive Phenomena at Ronez," *Proc. Geol. Assoc.*, vol. xlii, 1931, pp. 197-8) are of a similar opinion, the Jersey mantled felspars "reflecting the increased basicity of the magma as contamination progressed."

Backlund (*loc. cit.*, p. 367) has remarked that "no routine explanation based on the usual conceptions of 'magmatic' behaviour satisfies all the implications disclosed by close examination of the ovoids." Of course, there is no reason why there should not be formidable problems in magmatic crystallisation which cannot be explained by the magmatists, though, when present at their councils, I have formed the impression that this possibility had not often been realised. We can suppose, if we so please, that the complexities of the rapakivi texture, though unexplained, are clearly those of a magmatic environment. If that is so, the texture is a witness of a complicated series of events occurring in the consolidation of the melt and requiring a complicated series of physico-chemical controls. Now I would brutally recall once again that similar rapakivi ovoids occur isolated in the country-rocks—an occurrence everyone admits. Are we to believe that the complicated physico-chemical controls operate also in the country-rock environment in exactly the same way as they did in the consolidating magma ? We may do one of three things in reply to this question : we may, as is commonly done, happily ignore it ; we may, as Sederholm did, talk at large of the permeation of the country-rock by the granitic magma and consider that the differences in environment are in some way reduced ; or we may decide that since the country-rock in which the ovoids occur has clearly not been a magma from which they could have consolidated, then we must query the magmatic status of the rapakivi granite itself. We shall see in the next section of these remarks that exactly the same question is raised by all types of felspathisation. The rapakivi granites raise it in a more striking but not in a different fashion.

I resume the discussion on the genesis of the Fennoskandian rapakivi granites by a survey of the debate between Backlund and Von Eckermann, with Wegmann and others intervening, which enlivened the North in 1937 and 1938. The debate was opened by Backlund in his " Die Umgrenzung der Svekofenniden." *Bull. Geol. Inst. Upsala*, vol. xxvii, 1937, pp. 219-269 (written 15/1/37), continued by Von Eckermann in " The Genesis of the Rapakivi Granites," *Geol. Fören. Förhandl.*, vol. 59, 1937, pp. 503-524 (MS. received 2/12/37), stoked up by Backlund in " The Rapakivi Puzzle, A Reply," *ibid.*, vol. 60, 1938, pp. 105-112 (MS. received 1/2/38), fanned by Von Eckermann in "The Rapakivi Facts, An Answer to a Reply," *ibid.*, vol. 60, 1938, pp. 113-115 (MS. received 16/2/38), spread by Backlund in " Zur ' Granitisationtheorie ' ; Eine Verdeutlichung," *ibid.*, vol. 60, 1938, pp. 177-200 (MS. received 3/3/38) and blazoned abroad by him in "The Problems of the Rapakivi Granites," *Journ. Geol.*, vol. xlvi, 1938, pp. 339-396 (written 12/8/37). I give the bibliographical details so that any person of low tastes who likes to see the feathers fly may do so.

Backlund used that most exasperating opening, the re-interpretation of another man's ground. The Râtan and Rapakivi granites which Von Eckermann had described in great detail in the Loos-Hamra district of Sweden were interpreted by Backlund as granitised sediments of molasse facies (*op. cit.*, 1937, p. 247). Differences between Von Eckermann's Swedish granites and the Finnish rapakivis were due to variation in the original sediments in the area of deposition ; the Åland Islands rapakivi, intermediately situated, had an intermediate composition. We can form some idea of Backlund's arguments by Von Eckermann's immediate and forceful reactions.

Von Eckermann (" The Loos-Hamra Region " *Geol. Förens Förhandl.*, vol. 58, 1936) had shown that the Jotnian igneous rocks formed a magmatic assemblage with its most acid members genetically connected with its most basic and that the Rätan granite was a forerunner of this magmatic province. Backlund's proposals, of course, broke up the unity of this assemblage ; the Rätan and rapakivi granites were not magmatic and had no connection with the basic Jotnian eruptives. Von Eckermann ("The Genesis of the Rapakivi Granites," *Geol. Fören. Förhandl.*, vol. 59, 1937, pp. 504-6 and pp. 517-520) leads off with the devastating counter that his fieldwork conclusively demonstrates that the rapakivi granites and associated rocks weather and disintegrate to make the basal arkoses of the Jotnian sediments ; according to Backlund such sedimentation-contacts are misleading—they really represent the limit of the migmatisation front rising from below. Von Eckermann follows up by some fast chemical work ; the graphing of analyses of acid and basic Jotnian eruptives from five widely separated developments shows, in Von Eckermann's words (*loc. cit.*, p. 508) " the utter improbability of the granitisation of anything as unhomogeneous as the basal Jotnian sediments conforming at five far-removed localities to the strict laws " that govern " true magmatic differentiation sequences within a magmatic province " : further, by comparison of the chemical compositions of rapakivi granites and of the sediments from which Backlund considers that have been formed, Von Eckermann shows that " if we accept the granitization theory, we are forced to assume a mystic hydrous alkaline fluid, partly very rich in fluorine and titanium " (*loc. cit.*, p. 513). This fluid, as calculated by Von Eckermann, is considered by him to be quite unlike that established as active in the granitisation of the Archean. I feel compelled to interject here that in my opinion this last statement of Von Eckermann's is rather wide of the mark. Von Eckermann holds (*loc. cit.*, p. 514-5) that the rapakivi texture is " a typically magmatic one " and that " in magmatic rocks retrograde felspar-crystallisation is no rarity " ; the peculiar features of the ovoids arise from "disturbed phase equilibrium (concentration, pressure, temperature) in the course of magmatic crystallisation " (*loc. cit.*, p. 515). In such undisturbed, non-metamorphic, sediments as the Jotnian sandstones it should, Von Eckermann holds, be possible to obtain " records within the surrounding rocks of either the transforming solutions, or their roads of transport "—such records are not forthcoming (*loc. cit.*, p. 515). Further, rapakivis are known with roof or floor of Archean rocks ; are we to suppose in this case, asks Von Eckermann, that the Jotnian sandstone parent of rapakivi was deposited in a cave in the Archean ? (*op. cit.*, p. 516). How can Backlund account for the chilled edges of rapakivi porphyries and the occurrence of such rocks well below the horizon of the Jotnian sandstones? (*loc. cit.*, p. 530). Moreover, the Rätan granite shows typically intrusive contacts (*loc. cit.*, pp. 522-3). Finally, Von Eckermann enquires as to what was the origin of all the sedimentary material which has been changed into granites, and as to where have come the mystic fluids that did it. Though granitisation may be valid in other fields than the Jotnian, he considers it (*loc. cit.*, p. 524) " a waste of time to build theoretical granitisation structures on the quicksands of the Jotnian." The first round, I consider, goes to Von Eckermann on points.

Buckland opens the second round (" The Rapakivi Puzzle, A Reply," *Geol. Fören. Förh.*, vol. 60, 1938, pp. 105-112) by a disarming talk on temperament, and follows by a statement on what he considers his task to be. This is, first, to demonstrate that granitisation is not a process confined to remote periods and great depths but is one appropriate to all fold-belts, second to direct attention to the biggest problem in regional geology, the space problem, and third to present some idea of the qualitative and quantitative aspects of the granitisation process. He maintains that his studies, including those of Von Eckermann's ground, show that Sederholm's ichor could not represent the granitising matter and that this must have varied with the rocks undergoing granitisation ; emanations is a better term to use than ichor and the mechanism of its migration has been suggested by Wegmann and others, as we have seen. The demonstration of these three points has been Backlund's purpose in his studies. He proceeds to show that Von Eckermann's chemical calculations for Jotnian granitisation are exactly in line with those for Archean granitisation ; Von Eckermann's calculations, indeed, " merely prove that (Backlund's interpretation) is entirely consistent with the results of detailed research elsewhere " (*loc. cit.*, p. 108). This is, in my opinion, a true statement. Backlund (*loc. cit.*, pp. 109-110) allows his thesis to be broadened ; rapakivi-like granites occur in the earlier Pre-Cambrian and are admitted to be formed from sediments not of the molasse facies ; rapakivi granites may be derived from Archean crystalline rocks,— " caves " of Jotnian sandstone are not necessary and some rapakivi granites were not necessarily formed from sediments. He insists that the supreme problem is that of space ; granitisation solves this problem, whereas an appeal to a gigantic magma in which the operations of magmatic differentiation may proceed is contrary to geophysical evidence and, likewise, an appeal to the derivation of the great rapakivi granites by differentiation from basic magma is contrary to geological evidence (*loc. cit.*, pp. 110-111).

Backlund concluded by thanking Von Eckermann for the new facts which he had provided, and thus possibly gave him an opening for his reply " The Rapakivi Facts ; An Answer to a Reply," (*Geol. Fören. Förh.*, vol. 60, 1938, pp. 113-115). Von Eckermann opens in dashing style with the remark that one man's puzzles are another man's crystal-clear facts. He denies that any space-problem exists for the rapakivi granites as they have domed their roof, or have been emplaced by areal intrusion or by block adjustments. Moreover, in Von Eckermann's own area, the greatest space-problem is that of the basic rocks which does not appear to bother Backlund at all. The basic pole of the rapakivi series is present as the Jotnian diabases in sufficient quantity to satisfy the requirement of derivation of the granitic from the basic magma. The alternation of horizontal, supposed granitised, sediments with basic eruptives and completely non-metamorphic arkoses is so far unexplained by Backlund and until this and similar problems are solved, Von Eckermann does not propose to take " camouflaged rapakivi-sediments " seriously.

In a previous paragraph I noted the view of Backlund that the granitising material must have varied with the rocks undergoing granitisation. Von Eckermann (*loc. cit.*, p. 114) seizes upon this and says " he (Backlund) gives no explanation of the geophysical laws which allow the different sediments to order by special delivery from the ascending migmatization-front their own exclusive transmuting emanation." He doubts that sediments have " such discriminating ability in choosing a suitable metamorphosing partner." This statement reveals, in my opinion, that Von Eckermann has completely missed one essential point about the granitisation process. Von Eckermann's criticism has been well met by MacGregor and Wilson (" On Granitisation and Associated Processes," *Geol. Mag.*, vol. lxxvi, 1939, pp. 207-8), who say : " During metasomatism such rock types as are already saturated for one or more components will not show any reaction to those particular components should they be present in the penetrating medium. Different sediments *will not have* to order by special delivery from the ascending migmatization front their own exclusive transmuting emanation. Rather they take their pick of a selection brought around on approval, and give in exchange equivalent amounts of those commodities which the new purchases are expected to replace."

During the Backlund-Von Eckermann debate, a general paper by Backlund had been awaiting publication in America. In this paper, " The Problems of the Rapakivi Granites," *Journal of Geology*, vol. xlvi, 1938, pp. 339-396, there is a good presentation of Backlund's thesis specially suitable for readers not particularly well informed in the details of Fennoskandian geology. There is no need here to summarise the contribution and I present only two aspects. The first concerns the influence of the structure and textures of the Jotnian sediments on the rapakivi granite resulting from their replacement. Diffusion of the emanations, Backlund proposes (*loc. cit.*, pp. 392-3), would be controlled by the bedding planes and the isothermal planes ; both controls are horizontal so that the resultant rapakivi granites are flat sheets. The porosity of these sediments of molasse facies facilitates permeation and the formation of rather homogeneous bodies of replacement origin. The original sediments are bedded and graded ; sharp boundaries to the rapakivi are produced by the influence of this grading, whilst traces of the original bedding are preserved in the granite as a series of equidistant horizontal planes characterised by mineral concentrations different from those of the general rock. Patches in the rapakivi crumble due, Backlund supposes (*loc. cit.*, pp. 358-9, 393), to an original variation in permeability so that certain patches of the sandstone were, so to speak, " unwetted " by the emanations, and thus did not receive their final " cementing " material—such patches accordingly were not transformed into really good rapakivi. Secondly, in this general paper, Backlund (*loc. cit.*, pp. 391-2) details the course of the transformation of the arkose into rapakivi granite ; it is controlled by fluctuations first in temperature and second in the chemical nature of the metasomatising emanations. Crystallisations, intergrowths, resorptions, replacements and reorganisations become possible so that the complexity of texture of the rapakivi granites results.

To the onlooker outside the ring it appears that during this debate Backlund permitted certain portions of his thesis to be considerably widened and generalised whilst Von Eckermann had maintained fairly intact his Loos-Hamra position. One of the many difficulties that confronts the non-Fennoskandian enquirer in this matter follows from the employment of rapakivi in a geological sense as indicating certain granitic rocks late in the Pre-Cambrian sequence. With these geological implications I cannot here be concerned ; for my part, I have simply to remark that such of the Finnish rapakivi granites as I have seen in the field are on the field evidence reasonably interpreted along the lines of Backlund's granitisation proposals—such granites, I hasten to say, were not seen by me in contact with Jotnian Sandstone but with metamorphic rocks of one kind and another. I consider we should distinguish two problems ; the first is concerned with the origin of the rapakivi rocks from the Jotnian sediments at a given time in geological history, and the second with the origin of granitic rocks having characters like the rapakivi rocks of Fennoskandia. Whilst the first problem is rightly capable of arousing violent passions in Fennoskandia, it is the second problem which more closely and calmly concerns us now. What of the rapakivi-like rocks of any age or place ?

We have seen that Backlund agreed that rapakivi-like rocks occurred of various ages and with varied associations. In the discussion of the genesis of such rocks I have opportunity only to dwell upon the relevant work of Wegmann in South Greenland (" Geological Investigations in Southern Greenland, Part I," *Medd. om Gronland*), Bd. 113, No. 2, 1938). Wegmann (*loc. cit.*, pp. 98-121) found that many granitic massifs in Southern Greenland are surrounded by a zone of rapakivi granite which is transitional into the metamorphic country-rock, gneiss, amphibolites, etc. The rapakivi-type does not occur without the presence of fragments of country-rock ; this association gives a structure like Sederholm's agmatites or eruptive breccias, and Wegmann speaks of an agmatitic front. He says (*loc. cit.*, p. 118) : " the rapakivi texture occurs in the agmatitic front, which forms a shell round the syenitic massifs." He describes and figures beautiful examples of xenolith-rich rapakivi granite with rapakivi felspars developed in the xenoliths. He concludes that all the field-evidence " speaks in favour of a metamorphic origin " of the rapakivi texture. The previously existing rocks have been transformed into rapakivi-like rocks by the advance of the agmatite front, " such agmatites are found when the roof is much jointed or in other ways contains beaten tracks along which the volatile components may prepare for action " (*loc. cit.*, p. 117). Wegmann cannot agree with Backlund in his original view that molasse sediments are necessary for rapakivi formation as he finds rapakivi granite produced in Greenland from " very different original rocks of very different ages " (*loc. cit.*, p. 117). Nor can he agree with Von Eckermann with regard to the supposed absence of pegmatites from the rapakivi granites ; he says " pegmatites are not absent from the Rapakivi, but the pegmatitic material forms part of this rock " (*loc. cit.*, p. 120).

It is now therefore reasonably well established, in my opinion, that rapakivi-like granitic rocks may arise by a variety of felspathisation. We have already briefly noted evidence for this view from Finland and from Greenland and we shall obtain more in the next section of these remarks. I cannot forbear, however, to present one further piece of evidence from Unst in the Shetlands which, fittingly enough once Norse, is now geologically mine. From Herma Ness in Unst, L. J. D. Fernando ("Petrology of Certain Felspathised Rocks from Herma Ness, Unst, Shetland Islands," *Proc. Geol. Assoc.*, vol. lii, 1941, pp. 110-130) has described "augen granites" with large mantled rapakivi felspar ovoids (*loc. cit.*, Plate 7, Fig. C). Fernando concludes from his detailed investigation that "the rapakivi texture, at least as far as the Herma Ness rocks are concerned, is intimately connected with replacement associated with the general process of felspathisation. It is evident that the rim of plagioclase is clearly a replacement rim, and the corrosion of the potash felspar is just as evident" (*loc. cit.*, p. 123); "these rapakivi rocks represent arrested stages in the replacement of potash by soda" (*loc. cit.*, p. 128). Many examples could be produced of the formation of rapakivi-like felspars in xenoliths. I would remind you of my query of an earlier page: are we to believe that, as illustrated in the formation of rapakivi texture, complicated physico-chemical controls operate in a country-rock environment exactly in the same way as they do in a magmatic environment? For some examples, the answer is clear—there are not two environments, but one environment. We look into this answer both in general and in particular in the next section of this Address.

VI. BIG FELSPARS AT GRANITE CONTACTS.

In our survey of the French School, and especially of the work of Fournet, Delesse, Michel-Lévy and Lacroix, we saw that the expression felspathisation was in constant employment from the earliest times to indicate happenings at granite contacts during which felspars were produced in quantity in the country-rocks. Fournet (*Die Metamorphose der Gesteine nachgewiesen in den westlichen Alpen*, Freiberg, 1847, p. 72) discussed the problem in connection with the modification of clay-slates by plutonic action. He notes, as we have already seen, that since such rocks contain potash soda and lime it is possible for felspars to arise in them by simple recrystallisation; at times, however, so much felspar is developed that an impregnation with felspar by some kind of capillary action must have taken place. It seems clear that many of the French used felspathisation and granitisation as almost interchangeable terms; Delesse is explicit on this point. After all, felspars are simply the most noticeable of the newly formed minerals in rocks undergoing granitisation. I have already discussed felspathisation in this sense and now I may take up for the most part the consideration of a special topic, namely, the appearance of large felspars in the country-rocks at granite contacts—a topic which I have introduced in the account of the rapakivis. Before I do so, however, there are certain critics of the general thesis to be dealt with and a few unquestionable examples of it to be outlined.

Harker (*Metamorphism*, 1932, p. 250) stated that felspathisation is "the supposed impregnation on an extensive scale of metamorphosed rocks with felspar derived from a magmatic source." He continued: "This hypothesis dates from a time when the formation of various felspars as normal products of metamorphism was not adequately appreciated," and he held up as a warning to the believers in felspathisation the detailed results of Goldschmidt at Stavanger where in the country-rocks adjacent to the granite "there has been some accession, not of felspar, but of soda and silica" and where, too, "it appears that the actual diffusion of material does not surpass a very moderate range." I submit first, that the formation of felspars during metamorphism without transfer is a fact admitted by all; we saw in a previous paragraph that it was admitted by Fournet, the classic protagonist of felspathisation, nearly a century ago.

Secondly, I submit that these felspathic "normal products of metamorphism" are not like the felspar-porphyroblast schists and augen-gneiss so common in the migmatite areas. Further, whatever felspathisation once meant, I maintain that it does not now mean an impregnation with felspar derived from a magmatic source. In felspathisation, material for the formation of felspar may be contributed both by the country-rock and by the introduced solutions, magmatic or otherwise, as we see illustrated immediately. For me, felspathisation means that aspect of granitisation in which attention is directed to the formation of felspar. As Harker did, Niggli ("Das Problem der Granitbildung," *Schweiz. Min. Petr. Mitt.* Bd. XXII, 1942, p. 29) also stresses the fact that an apparent "enrichment in felspar" may take place without the slightest change in the bulk composition of the rocks. Many gneisses, he states, have the same chemical composition as mica-schists, and whether much or little felspar has developed is a consequence of the physical and not of the chemical conditions.

The answer to this line of criticism was, as we have seen, also given by Fournet—at times so much felspar appears that felspathisation *must* have occurred. It will be profitable, I think, to look into a few simple cases so that we may be sure of the reality of felspathisation—remembering that I have defined this as the formation of felspars in rocks undergoing granitisation. Of the innumerable examples supplied by the French School I select the classic case described by C. Barrois (" Mémoire sur le granite de Rostrenon ," *Ann. Soc. Géol. Nord.*, vol. XII, 1884) from the Rostrenon granite, Côtes-du-Nord. A figure on p. 14 of Barrois' *Mémoire* shows irregular veins of porphyritic granite in micaceous greywacke in which are developed numerous large crystals of orthoclase, " disséminées au hasard, à la facon des andalousites dans un schiste, au voisinage du granite."

Our next example of felspathisation is V. M. Goldschmidt's demonstration in the Stavanger region. This is a particularly good example as it is described in detail, is backed by analyses, and is illustrated by self-explanatory plates of rock-specimens. At Stavanger the regionally developed quartz-muscovite-chlorite-phyllites are transformed into albite-porphyroblast schists and augen-gneisses. The albite-porphyroblast schists ("Die Injektions-metamorphose im Stavanger-Gebiete," *Vidensk. Skrift. I. Mat. naturv. Klasse*, 1920 (1921), No. 10, pp. 81-87) are obviously the result of felspathisation, as a glance at Goldschmidt's magnificent Plates III (Fig. 2), IV (Figs. 1 and 2) and X (Figs. 1 and 2) would show. These schists occur as layers in garnet-mica-schists, as compact independent rock-masses or as stripes in injection-gneiss. They show porphyroblasts of oligoclase-albite, Ab72, in a matrix of quartz, muscovite, biotite and garnet. By the appearance of potash-felspar they pass with advance of felspathisation into augen-gneisses (*op. cit.*, pp. 87-99). Consideration of the chemical analyses of the whole Stavanger series shows that the albite-porphyroblast schists and augen-gneisses are produced from the phyllites by an influx of alkalies, lime and silica (*op. cit.*, pp. 108-115). The progress of this influx is revealed by the increase in plagioclase felspar from some 10-12 per cent. to 30 per cent. This felspathisation is a typical metasomatic process.

For our next example of felspathisation and granitisation we may consider that provided by G. H. Anderson from the Inyo Range (" Granitization, Albitization and Related Phenomena in the Northern Inyo Range of California-Nevada," *Bull. Geol. Soc. Amer.*, vol. 48, 1937, pp. 1-74). Anderson shows that the Mesozoic batholithic granites of the Sierra Nevada are represented by two strikingly different types; one, the Boundary Peak granite, is a white uniform biotite-granite, with nothing about it that would suggest that it "was formed in any other way than by crystallization from a magma " (*loc. cit.*, p. 73). The second type, the Pellisier granite, occurs between the Boundary Peak granite and the overlying country-rocks, limestones, argillites and schists ; it is a dark grey porphyritic rock, very variable in texture and composition, and contains innumerable xenoliths. It is considered by Anderson to be formed in situ by the recrystallisation of the country-rocks with the addition of more or less material from a subjacent magma—the Boundary Peak granite being the source of the emanations. It is worth while giving a summary of the arguments advanced for this granitisation origin ; they are (*loc. cit.*, pp. 45-7) :

(i) Similarity in composition and texture between the Pellisier Granite and the partly recrystallised and replaced rocks of the contact zone ; (ii) gradational contacts between the Pellisier Granite and the older rocks ; (iii) digestion of xenoliths observable in the granite ; (iv) variability in texture and composition ; (v) its 'stratification' structure which can, in places, be traced into similar structures in xenoliths or country-rocks ; (vi) the grey colour of both Pellisier granite and the country-rocks is due to the same cause—dissemination of ferruginous material ; (vii) the granite shows an increase of biotite near biotite-schists ; (viii) the regional structural orientation is not changed in the xenoliths, and (ix) the Pellisier granite contains sillimanite and staurolite.

Especially important for our present enquiry is Anderson's demonstration of successive stages in the transition from biotite-schist to porphyritic granite (*loc. cit.*, pp. 37-38 ; Plate V, Fig. 1 ; Plate 6, and (especially) Fig. 7, p. 37). Along a canyon wall is exposed a section about a mile long displaying this transition and it is of interest to note that Anderson's Figure 7 of this section resembles Barrois' Rostrenon figure given half a century before. The process at Inyo begins with the formation of large porphyroblasts of potash-felspar, up to an inch across, within the schist, the matrix of which is but slightly altered. The next stage shows the appearance in the schist groundmass of sinuous bands of quartz and felspar along the foliation planes. This replacement proceeds till stringers of schist are distributed through a matrix essentially granitic ; the felspar porphyroblasts persist to the end of the process and here and there they are found partly enclosed in the granitic matrix and partly in the schist "inclusion." "In the final stages of the replacement the schist xenoliths disappear or become indistinguishable, and the rock is, to all appearances, a porphyritic granite with large phenocrysts, which commonly enclose biotite and quartz. A granite of this type is widespread in the northern Inyo Range" (*loc. cit.*, p. 38). Chemical investigation shows that in the granitisation process there has been again an influx of silica, lime and soda (*loc. cit.*, pp. 39-40).

Excellent cases of felspathisation have been described and figured from Southern Greenland by Wegmann ("Geological Investigations in Southern Greenland, Part I," *Medd. om Grønl.*, Bd. 113, No. 2, 1938). From his field observations on the development of felspar lenses, augen or porphyroblasts, Wegmann (*loc. cit.*, pp. 45-6) concludes that "the phenotype porphyritic granite may have different origins, and does not correspond to one single genotype." His description (*loc. cit.*, pp. 106-8) of the Sydproven granite is of very great interest for our present purpose. This granite is coarsely porphyritic, and shows a transitional zone into migmatites. "The transition is initiated by the formation of big felspars in the gneisses and amphibolites, which gradually gather into large clouds. . . . When the transformation proceeds along all routes there remains a swarm of inclusions whose orientation is still retained." Wegmann (*loc. cit.*, Fig. 59, p. 108) presents a photograph of a rock surface which deserves the closest study ; it has the explanation "The imbibition of the Ketilidian migmatites and transformation into younger granite," which is simply a statement of what can be observed. In an earlier account of the geology of part of North-East Greenland, Wegmann ("Preliminary Report on the Caledonian Orogeny in Christian X's Land" *Medd. om Grønl.*, Bd. 103, No. 3, 1935) described the felspathisation of quartzite. Nearly pure quartzites show more and more felspar as they are traced into zones of granitisation. For the felspar which occurs "in the texture of the quartzite" it is clearly necessary to assume a migration or impregnation of material by Termier's oil-spot mechanism. "Where quartzites and schists are interwoven with feldspar they have become gneisses or granites. . . . Not all the material has migrated, but only part of it, viz., precisely the part which rendered the formation of feldspar possible " (*loc. cit.*, p. 23).

Many examples of felspathisation—cases which I do not hesitate for one moment to describe as excellent—have been given by myself and my students from Scottish migmatite areas. Thus L. J. D. Fernando (" Petrology of Certain Felspathised Rocks from Herma Ness, Unst, Shetland Islands," *Proc. Geol. Assoc.*, vol. lii, 1941, pp. 110-130) has described and figured augen-granites and augen-gneisses formed by the soaking of sodic and potassic magmatic fluids into mainly semipelitic country-rocks in Unst. A glance at the two plates which accompany Fernando's account will convince anyone of the reality of felspathisation at Herma Ness. A dozen years ago I described the development of felspar augen in semipelitic rocks in the Central Sutherland migmatite area (e.g., H. H. Read, " The Geology of Central Sutherland," *Mem. Geol. Surv. Scotland*, 1931, pp. 116-118, Plate II, B and Fig. 8) and recently Y. C. Cheng has investigated the process in detail in North Sutherland (Y. C. Cheng, " A Hornblendic Complex, including Appinitic Types, in the Migmatite Area of North Sutherland, Scotland," *Proc. Geol. Assoc.*, vol. liii, 1942, pp. 67-85, especially Figs. 3 and Plate 2, Figs. 2 and 3 ; " The Migmatite Area around Bettyhill, North Sutherland," *Quart. Journ. Geol. Soc.*, vol. xcix, 1944, pp. 107-154, especially Figs. 4 and 7). Cheng has shown by the investigation of series of specimens collected dead along the strike of beds undergoing migmatisation that the production of permeation-gneiss is "essentially in the nature of felspathisation, with plagioclase forming in the present case "—the compositional changes according with those proposed for analogous rocks in Norway and America. Other cases of felspathisation are described by Cheng ; certain migmatitic derivatives of semipelitic rocks are shown to be due to the " circulation of potash-rich solutions along foliation planes with the formation of orthoclase from the pre-existing minerals, (but) a part of the potash needed to form the augen was undoubtedly derived in situ." In other semipelitic derivatives he shows, by petrological and chemical investigation, that felspathisation has again occurred with oligoclase as the chief product. Cheng doubts whether certain of his eruptive rocks are igneous in the real sense of the word. " The ' igneous ' sheets may be simply channels along which large amounts of magmatic fluids have repeatedly been introduced and have reacted with the surrounding country-rocks to form various kinds of granitic rocks." Almost all the changes observed by Cheng in his migmatites are considered to result from the metasomatic activity of rather attenuated alkaline fluids, and he works out an immense series of readjustments in his rocks consequent on the disturbances of chemical and physical equilibrium in them.

As my last sample of granitisation I cite the detailed study by Doris L. Reynolds (" Granitisation of Hornfelsed Sediments in the Newry Granodiorite of Goraghwood Quarry, Co. Antrim," *Proc. Roy. Irish Acad.*, vol. 48, B, No. 11, 1943, pp. 231-265) of hornfelsed Silurian sediments enclosed in the Newry granodiorite. In the first stage of the process, small irregular bodies of trondhjemite (oligoclase-granite) are formed in the hornfels by the fixation of incoming soda, lime and silica with the concomitant expulsion of magnesia and iron oxide. In a second stage, potash displaced in the first stage is fixed in microcline porphyroblasts and in bodies of granodiorite character. Once again it is demonstrated that the entry of soda, lime and silica initiates a complex series of chemical readjustments which lead to profound modifications of the original rocks.

In these typical examples of felspathisation and granitisation just presented, I have been careful to indicate many plates and figures for your inspection.

Though to " go and see " would be pleasant and profitable, especially at this time, these illustrations are I consider of sufficient validity to enable the ordinary reader to make up his mind on the reality of these processes. I have made a selection of the abundant evidence—I could have taken examples from dozens of workers from all over the world. Nobody except him who has learnt less and forgotten less than any Bourbon can deny the validity of the conversion "of solid rocks to rocks of granitic character without passing through a magmatic stage." We have noted incidentally that many of the early stages of the granitisations described are marked by the development of large felspar porphyroblasts in the rocks undergoing granitisation. We have now to consider this phenomenon more specifically and to discuss what I take to be its fundamental significance.

In earlier pages I have noted Fournet's observation of the growth of large felspar crystals in hornstones and Cotta's record of large crystals of orthoclase in diorite fragments enclosed in the Thuringerwald granite. I would remind you, too, of Michel-Lévy's " dents de cheval " from Flamanville—the great orthoclase crystals found in enclaves which are identical with those that give the surrounding granite its porphyritic appearance. I recall also the common occurrence of rapakivi mantled ovoids, with all their intricacies, in country-rocks adjacent to the rapakivi granites, as seen especially well in the Buckholm contacts in Finland and displayed very clearly by Wegmann in Southern Greenland. I have already twice asked what seems to me the fundamental question : are we to believe that, as illustrated in the formation of the rapakivi texture, complicated physico-chemical controls operate in a country-rock environment exactly in the same way as they do in a magmatic environment ? The rapakivi felspars raise this question in a particularly spectacular fashion, but the same question is raised by innumerable, and very likely all, porphyritic granites. I invite you when you leave this room to satisfy yourself of the reality of this question by inspection of the great expanses of Shap and Cornish porphyritic granites displayed along Piccadilly, Fleet Street, Victoria Street and most of the opulent streets of London. You will find, in almost every polished slab, dark xenoliths which display a few large felspars apparently identical with those of the enclosing granite. I take the case of the Shap granite for special enquiry.

The small Shap granite in Westmorland has been investigated by Harker and Marr (" The Shap Granite, and its associated igneous and metamorphic rocks," *Quart. Journ. Geol. Soc.*, vol. xlvii, 1891, pp. 286-328) and later by D. R. Grantham (" The Petrology of the Shap Granite," *Proc. Geol. Assoc.*, vol. xxxix, 1928, pp. 299-331). The granite is characterised by the occurrence of large pinkish orthoclases in a greyish, moderately coarse, matrix in which orthoclase, quartz, biotite and plagioclase are visible. In addition to obvious xenoliths, the granite contains darker and finer-grained rounded patches which were interpreted by Harker and Marr (*loc. cit.*, p. 291) as derived from an underlying more basic magma. In these dark patches are found large felspar crystals similar to those of the granite proper. As Grantham (*loc. cit.*, p. 326) has remarked, these crystals have been taken to be phenocrysts and therefore to prove that the dark patches are differentiation or segregation products of the magma. Grantham (*loc. cit.*, pp. 326-7) shows there is a detailed parallelism in microstructure between the basic patches and the metamorphosed andesitic country-rock and concludes that the large crystals are porphyroblasts crystallising from solutions introduced into the permeable andesite xenoliths, which themselves become highly metamorphosed and impregnated.

The Shap felspars have been studied by Edmonson Spencer (" The Potash-Soda-felspars, II, Some applications to petrogenesis," *Mineral. Mag.*, vol. xxv, 1938, pp. 111-113) who shows that the optical properties of the orthoclase porphyroblasts in the ' semipelitic ' xenoliths are identical with those of the orthoclase phenocrysts in the granite. It seems that there are not two felspars, but *one* felspar.

Spencer (*loc. cit.*, pp. 113-4) passes on to study the large felspars which occur in xenoliths of Malmesbury shale in the Kloof granite of Cape Town, and the xenoliths and granite themselves. His conclusions are worth quoting :

> " It is interesting to observe that if the metamorphism of this particular xenolith had been carried to the stage of complete holocrystalline reconstitution, with homogenization of the felspar porphyroblasts, but without actual fusion, the result would have been a rock closely resembling—if not identical with—a porphyritic potash-rich granite " (*loc. cit.*, p. 114).
>
> " The occurrence of potash-soda porphyroblasts in xenoliths and similar metamorphosed rocks under conditions which preclude an origin by direct consolidation from a magma, raises the question as to how far it is justifiable to regard holocrystalline rocks, even of typical granitic appearance, as products of direct magmatic crystallization. The same process which gave rise to the porphyroblasts, if continued for longer periods or at elevated temperatures, might produce holocrystalline granitic rock structures without the mass having even approached the liquid state " (*loc. cit.*, p. 115).

In their account of a Jersey granite, A. K. Wells and S. W. Wooldridge (" The Rock Groups of Jersey, etc.," *Proc. Geol. Assoc.*, vol. xlii, 1931, pp. 197-98) make a reference to the Kloof granite contacts just mentioned. They note that the modified granite at Sea Point, Cape Town, bears a striking resemblance to a contaminated rock at Ronez, Jersey, " particularly in respect of the highly idiomorphic porphyritic felspars that become increasingly prominent the more foreign matter has been assimilated." Wells and Wooldridge found it difficult to believe in some cases that these South African porphyritic felspars " have not originated in the country-rock rather than in the granite, although it is not easy to provide an adequate explanation of their genesis on these lines." They *can* believe, however, that the porphyritic felspars in the Jersey rocks are largely of granitic parentage, as " proved by certain pink crystals zoned with a thin white mantle . . . . seen to consist of a potash felspar interior with a surround of oligoclase, thus reflecting the increasing basicity of the magma as contamination progressed." Readers of these remarks of mine will be able to estimate the validity of this *proof*.

Certain phenomena very like those described by Grantham from the Shap granite were encountered by H. H. Thomas and W. Campbell Smith (" Xenoliths of Igneous Origin in the Trégastel-Ploumanac'h Granite, Côtes du Nord, France," *Quart. Journ. Geol. Soc.*, vol. lxxxviii, 1932, pp. 274-296) in the Trégastel granite and were explained in quite a different way. At Trégastel, basic igneous xenoliths in the granite carry large felspars " identical with the felspars of the granite " (*loc. cit.*, p. 289). These felspars and " even composite fragments of granitic material " were derived from the granite (*loc. cit.*, p. 286). Though " typical igneous structures are preserved in the basic mass throughout all the phases of hybridisation . . . a certain degree of fluidity was produced (as) shown by the presence well within the margin of the basic hybrids of xenocrysts of felspar and of actual granitic material (which) must have been derived in their present condition from the granite and introduced mechanically into the hybrid rocks " (*loc. cit.*, pp. 289-290). Thomas and Campbell Smith agree, in this mechanical forcing-in of the felspars, with the earlier opinion of Grenville Cole (" On derived Crystals in the Basaltic Andesite of Glasdrumman Port, Co. Down ," *Sci. Trans. Roy. Dublin Soc.*, Ser. 2, vol. v, pp. 239-48) and Harker (*Tertiary Igneous Rocks of Skye*, *Mem. Geol. Surv.*, 1904 p. 219). They cannot agree for instance with Grantham's opinion that the crystals of orthoclase at Shap have grown within the xenoliths.

This is a matter on which the field-evidence shows there can be no kind of doubt whatever. Records of hundreds of field exposures show that the felspars *cannot* have been " introduced mechanically." In the Trégastel examples themselves, the " igneous structures are preserved " in the xenoliths. There springs to my mind the case of very large sharp-edged xenoliths of semipelitic rock in the Skaw porphyritic granite of Unst in the Shetlands (*Proc. Geol. Assoc.*, vol. liii, 1942, p. 107) ; in the midst of the xenoliths are large felspars inches across identical with the porphyritic felspars of the granite, but the delicate bedding, displayed often in three dimensions, is not disturbed in the least. A felspar " introduced mechanically " must in these examples have covered up its tracks pretty well.

The inability of the magmatists to interpret the plain field-facts arises of course from the inertia of a century of belief in the magmatic origin of all granitic rocks. This inertia has been increased for many by the addition of weighty physico-chemical arguments which 'explained' the phenomena. It takes a certain amount of courage to cut adrift from authority and to go round to the other side of these problems and look at them from a completely different direction.

We have seen that it is inherent in the view of the magmatists that, first, porphyritic granites consolidate from a magma and that, second, enclaves containing similar porphyritic felspars must be differentiation or segregation products of that magma. The large felspar crystals become the touchstone of magmatic origin of the rock containing them. Something might be said for such an argument so long as the enclaves in question were anything like the igneous rocks ; for example, Harker and Marr, as we have seen, contentedly derived the dark more basic patches in the Shap granite from an underlying more basic magma. The argument completely collapses, however, when the enclaves which contain the touchstone felspars are unquestionably of sedimentary origin ; it has, in fact, to be put into reverse, unless we take refuge in a mechanical introduction for them. It now runs thus : because the enclaves containing the felspars are sedimentary, then what encloses the xenoliths and similar felspars is also sedimentary—the porphyritic granites are produced from sediments by an intensification of the felspathisation process. Both ways of the argument depend upon the identity of the felspars, and this has been definitely proved in numerous cases. Is the sedimentary argument any more valid than the now discredited magmatic argument ? It is, because though we can demonstrate the sedimentary origin of the key enclaves, no one can *demonstrate* the magmatic origin of the porphyritic granite which contains them. Niggli (*loc. cit.*, p. 6) has made play with the fact that lavas of granitic composition are abundant ; this fact does not, however, prove the existence of a granitic magma—it simply records that lavas of granitic composition are abundant.

One can, of course, believe that the two sets of felspars, though admittedly identical, are really formed in two quite different environments, one magmatic and the other solid rock. I am tempted to remark, as the Duke of Wellington did on another occasion, that if one can believe this, one can believe anything ! If this is really true, in view of the profound differences in the environments, I feel that a great part of the lore about magmatic crystallisation becomes meaningless. I consider it more reasonable, and in the ultimate more honest, to hold that there is only one environment, that of the solid country-rock.

Throughout these discussions we have kept before our eyes the phenocrysts, or the porphyritic crystals, or the porphyroblasts of potash-felspar, and we have done so because these, as their names denote, are the most spectacular elements for observation. We must remember, however, that smaller and less noticeable but just as important elements have to be considered. I refer, for example, to the appearance of acid plagioclase and possibly quartz in the Shap enclaves (Grantham, *loc. cit.*, p. 326) ; these appear, too, in the Skaw xenoliths and have been recorded from numerous other xenolithic contacts. Further, depending upon the nature of the country-rock, a ferromagnesian mineral such as biotite or hornblende arises. With the continuation of the formation of this typical granitic assemblage, the country-rock xenolith is gradually made over to a granite ; I recall Spencer's note on the xenoliths of Malmesbury shale in the Kloof granite, for example. To satisfy yourself of this, examine carefully the next *large* polished slab of Shap or Cornish porphyritic granite that you come across. There is nothing mysterious or complex about these proposals provided we look at the matter in the right way.

Any reasonable person will admit, if he takes the trouble only to examine the diagrams and plates illustrating the relevant papers cited in this and the previous section of this Address, that granitisation is valid in the great migmatite complexes. We have by now admitted also, I trust, that even in the case of the apparently 'igneous' granites, the "proper" granites or the "real" granites as they are often called, granitisation may also be valid. Many of these "real" granites appear to be eruptive, they evoke the idea of eruptivity by their mode of occurrence, "leur apparition parait soudaine," as de Lapparent would say (*Lecons de Pétrographie*, 1923, p. 79). Granitic rocks formed by granitisation can, and indeed often do, evoke the idea of eruptivity—they certainly appear suddenly. We may recall Wegmann's view that where the granitisation front is stationary, sharp contacts will be formed which are, however, not intrusive contacts. Circumstances of temperature, pressure or concentration may give rise to knife-edge boundaries to the products of the granitisation reactions. Some granites, however, are held to come into place by intrusion. Is it possible for the products of granitisation to be made to move or to flow either as a migma or a magma ? If this is possible, then there may be a great connected family of granitic rocks—a family including granitisation products, migmatites and magmatites. We examine this possibility in the next section of these remarks.

VII. MOBILISATION.

In intrusion there must be movement of material. Wegmann, ("Zur Deutung der Migmatite," *Geol. Rund.*, vol. xxvi, 1935, p. 315) in his discussion of terms associated with the study of migmatites to which I have already referred, defines intrusion as the entrance of magma into spaces which it opens. Admittedly, many intrusions are of magmatic or migmatitic material (however these may be defined), but it is well to remind ourselves that a variety of other rock-materials—rock salt, cornstone, limestone, clay and so forth—can show intrusive relationships. The movement need be only of the smallest dimension—the conditions of intrusion or eruptivity are as well fulfilled by a movement of a centimetre as by one of a kilometre. If the movement is on a considerable scale the result may be, as Delesse stressed in 1869, that the intrusive body has been detached from its original genetic environment and appears in a new mechanically caused setting. This point cannot be over-emphasised ; it must constantly be borne in mind in all discussions of contacts. Consider for example, such contacts as those described and figured by Harker from Skye (*Tertiary Igneous Rocks of Skye*, *Mem. Geol. Surv.*, 1904, pp. 98-9, 132-5, and Figs 20, 29, 31). In these, gabbro or granite shows extremely sinuous contacts with limestone ; the shapes of the limestone remnants undoubtedly indicate (to me, that is) corrosion and replacement by magma ; the fact that neither the gabbro nor the granite show any signs of contamination with limestone indicates (to me, again) that such products of interaction between magma and limestone which were once at the contacts have now moved on to some other position. It is an entertaining thought that these undoubtedly remarkable reaction products may present, in their new position, problems perfectly insoluble on the local contact evidence.

With reference to our own special enquiry concerning how to get the products of granitisation to become intrusive, I may recall certain statements in previous pages of this present address and also of its forerunner last year. We have seen that Wegmann, for example ("Beiträge zur Kenntnis der Svecofenniden in Finnland, I.," *Bull. Comm. Géol. Finlande*, No. 89, 1931, p. 58) suggested that the Hangö granite was mainly a rock mass soaked with granitic solutions ; where the products of this soaking remained in the position of their formation, we have an area of granitisation ; soaking, however, may give the soaked mass the power of movement and if this occurs with sufficiently resistant walls a granite intrusion may result. We may recall, too, Wegmann's proposals ("Zur Deutung der Migmatite," *Geol. Rund.*, vol. xxvi, 1935, pp. 334-8) for recrystallisation in the highly compressed arches of the infrastructure with the result that granitic stocks break through the folded gneisses. With continued kneading and recrystallisation of the infrastructural tongues, all signs of their migmatitic origin may be lost by the resultant granitic intrusions. In the deep zones intrusive rocks reach their places by virtue of three qualities of movement —molecular movement of material, folding movements with the country-rocks, and marginal movements ("Geologische Merkmale der Unterkruste," *Geol. Rund.*, vol. xxvii, 1936, p. 45).

If we cast back to my remarks of last year ("Meditations on Granite : Part One," *Proc. Geol. Assoc.*, vol. liv, 1943, pp. 70, 71) we note that the Lake District School of Clifton Ward and Green considered that increase in the degree of the metamorphism in granitisation would lead to intrusion. Ward, for example, states that "a granitic mass formed by metamorphism of rocks *in situ* is almost sure to become an intrusive mass *at some part*" (*Quart. Journ. Geol. Soc.*, 1876, p. 30). We may remember, too, Green's three forms of granite, —bedded and amorphous granites, produced by metamorphism in place, and irruptive granite, "forcibly intruded into the rocks among which it occurs." This "irruptive behaviour may reasonably be attributed to an increased degree of energy in the metamorphic process which gives rise to it" (*Physical Geology*, 1882, pp. 450-1).

That the products of granitisation could move was a tenet of the early French school. Thus, for example, Virlet, in the 1847 volume which we have already examined, is explicit on this point :

> "Le surgissement de telle ou telle roche n'entrâinnent pas nécessairement toujours la conséquence d'une origine ignée, parce que le métamorphisme a pu, dans de certains cas, donner lui-même lieu et en agissant par pression sur les masses inférieures, à des surgissements analogues." (*Bull. Soc. géol. Fr.*, vol iv., 2nd Series, 1847, p. 505).

Let us again consult the Fennoskandians on this matter. As we have noted in an earlier page, Sederholm (*Migmatites*, II, pp. 134-5) held that "the ichor of the granite has been able intimately to penetrate the older rocks giving them a new 'palingene' eruptivity." Backlund, it will be recalled, has erected a series of stages of increasing mobility, with the end terms of migmatite, palingenite and diapirite, which result from the increased activity of ichors. He has considered this question of *mobilisation* at some length. Before I deal with his contributions, however, I should state that to me mobilisation is an ordinary English word with its ordinary meaning, namely, making movable. It will be a bad day when mention of mobilisation "is a bell to summon the fantastics." If a technical geological term is required (for, I feel, the purpose of confusing the issue) you may care for *rheomorphism* which is defined by Backlund as :

> "the whole process by which a rock is converted partly or entirely into liquid with the entry of more or less new material which has diffused in" (see original, *ante*, p. 73).

Backlund considers that granitisation leads to an increase in the amount of material in a given space and that this increase is small in the case of the pelitic host so that the granitisation products of this parentage remain in position, but in the case of limestones and quartzites, the increase is considerable so that the products become mobile and may form intrusions. In my opinion, the fundamentals of Backlund's argument are open to doubt ; since there are no great changes in the specific gravity of rocks on granitisation and since the geometry of the original rocks also is often little changed, I prefer to believe that if immigration takes place, emigration takes place also. The explanation of mobilisation is, I feel, not to be sought along these lines.

We may now examine certain British proposals on mobilisation. After their excellent exposition of the chemical and physical mechanism of the metasomatism involved in granitisation, M. MacGregor and G. Wilson ("On Granitisation and Associated Processes," *Geol. Mag.*, vol. lxxvi, 1939, pp. 210-2) proceed to discuss whether metasomatism alone can produce mobility. They remark that if sufficient intergranular fluid is produced, cohesion between the rock constituents will be lost. A mass composed of spherical grains would become mobile if 26 per cent. of its volume became liquid. In nature, with irregular grains, introduced fluxes and wet conditions, mobility would be more readily attained. Changes of temperature and pressure and the introduction of emanations into the already heated rocks assist in the development of mobility. It seems to me that proposals along these lines are entirely reasonable; there can be no question that such mashes of crystals and liquid could move on this kind of ball-bearings.

Dr. Doris L. Reynolds has on many recent occasions discussed mobilisation; I consider one ("The Two Monzonitic Series of the Newry Complex," *Geol. Mag.*, vol. lxxiii, pp. 337-364) as an example. She (*loc. cit.*, p. 355) makes reference to material which "is *igneous* only in the sense that its material temporarily attained mobility as a local result of ultra-metamorphism stimulated by the introduction of highly energized emanations." Sediments are considered to become endowed with the ability to move by a process of transfusion which is "essentially one of metasomatism due to emanations. The actual movement . . . . of the transfused sedimentary material is possibly to be attributed to either internal expansion, dependent on metasomatic additions (including energy), or to externally applied stresses" (*loc. cit.*, p. 355). The mobilised sediment "provides evidence of an arrested stage in the generation of magma" (*loc. cit.*, p. 358) and "the process of transference culminates in the development of magma" (*loc. cit.*, p. 360). For my part, I think I should prefer to use migma instead of magma in these last statements.

It would be mere diehard obstinacy to deny the possibility of mobility being induced in granitisation products by pore-magma, introduced fluids, increased temperatures and increased pressures. No one denies mobility in the phenomenon, mechanically somewhat analogous, of hill-creep and slumping. If, however, movement has occurred in the granitisation products so that they have become intrusive bodies, should not evidence of this movement be obtainable in the consolidated intrusive rocks ? A mash of crystals, lubricated with a rather small amount of fluid, is forced into a new position ; surely movement of material of this composite kind will be recorded in the texture of the final rock ? In the opinion of MacGregor and Wilson (*loc. cit.*, p. 210) "the complete fluidity of any major mass has never been conclusively demonstrated. In most cases a mobile mush of crystals and liquid would equally well account for the observed facts." This statement, I hold, is a true one. There are a great many textures in the crystalline rocks which can be interpreted in a variety of ways, depending upon the dominant belief of the observer. Further, in the mashes we have in mind, hot and soaked and communicating with active sources, there will be great opportunities for homogenisation. Lastly, undoubted evidence of flow of solids in fluids is available from many intrusive masses.

VIII. GRANITES AND GRANITES.

In the preceding section of this Address, I have considered what is in essence the production of migma. We must remember, however, that according to many observers magma, *completely fluid rock-substance*, may arise during granitisation. We have noted, for example, Sederholm's proposals concerning anatexis by which bodies of magma may be formed. We have noted also, now and last year, other suggestions on granitic magmatisation such as those of Hutton, of Lyell, or of Termier which favour an intensification of metamorphic processes, or that of Eskola of selective refusion. All such bodies of magma may be forced into other positions and there consolidate as igneous rocks ; they may form some of the puny cross-cutting granites of the higher levels. When in addition we recall also the proposals outlined in my Address of last year (pp. 78-80) concerning the formation of primary granitic magma by the melting or partial melting of the sialic layer, we realise that there may be, in Green's words, granites *and* granites.

It is my opinion, however, that in reality we do not have much freedom of choice amongst the many proposed origins of granite. Our choice is restricted by one gigantic problem, that of room—how do granite masses get into their positions ? In the case of small granites we may solve the problem along structural lines, by suggesting that doming, cauldron-subsidence, block-faulting or other mechanisms made possible the entry of granitic magma or migma. For large masses of granite, however, such solutions are impossible—no mechanism yet devised accounts for the intrusion of the gigantic volumes of magma there required. The only solution is to suggest that in fact no large bodies of granitic magma were in existence. The large granite masses result from replacement, they are granitisation products. Many of the small granites may of course also be of the same origin, but some of them may result from the consolidation of migma and some from the consolidation of magma. Thus, though there may be granites and granites, most of them are of one kind and all of them may likely be of one connected origin.

The attentive and pugnacious listener may interject that I am using the term granite in a scandalously loose fashion. Did I not, he may ask, define granite last year as a deep-seated igneous rock, and did I not define an igneous rock as one consolidating from a magma, and a magma as completely fluid rock-substance ? I reply that I did so define magma and igneous rock, but I protest that the definition of granite presented was that of the standard authorities and not mine. In my opinion, some few of the granites may be igneous rocks as I have defined them, but there are a great many granitic rocks which are not igneous. The definition of the Authorities is excellent for one group of granites, but is not valid for most. I decline to propose a new set of rock names because Authority has taken too narrow a view and has concerned itself with minor presentations of granite. If you take the trouble to turn back to the first page of Part One of these Meditations you will find an excellent definition of granite —excellent, I suspect, because it is provided by a man with little petrological knowledge. It is that given by the *New English Dictionary* : Granite is "*a granular crystalline rock, consisting essentially of quartz, orthoclase-felspar and mica, much used in building*." Here are all things necessary—any further limits are but shackles on the free spirit.

IX. RETURN TO LYELL.

In our examination of the work of the French School we saw that many prominent members thereof—Virlet, Élie de Beaumont, Delesse, Michel-Lévy, Termier, to name a selection—held that there was a close connection between granite-formation and regional metamorphism. De Beaumont, for instance, reiterated that the origin of mica-schists, gneisses and granites is one connected question—a vast problem of which the origin of granite is the kernel. . Again, Delesse and Termier considered that the formation of magma, intrusion and regional metamorphism were all effects of the same cause—high-energy transformation resulting in plutonic and metamorphic rocks. For Michel-Lévy, contact metamorphism confounded itself with regional metamorphism in the depths. As we have also noted, the same kind of idea is also favoured by many of the Fennoskandians. In Sederholm's opinion the great quantities of solvents required for large-scale regional metamorphism can only be obtained from subjacent eruptive masses. Modern Fennoskandians, expecially Wegmann and Backlund, propose that movement of the migmatite front leads to the generation of granitic rocks and the impression of regional metamorphism on great bodies of crust. The majority of geologists who have worked on migmatite ground see a close connection between granitisation or migmatisation and regional metamorphism.

This connection is a matter which I have discussed at some length (H. H. Read, " Metamorphism and Igneous Action," *Pres. Add. Sect. C. Brit. Assoc.*, Dundee, 1939, especially pp. 22-9 of the separate); there is no need to traverse the ground again—I make one quotation :

> " Out from the central theatre of granitisation there pass waves of metasomatising solutions, changing in composition and in temperature as they become more distant from the core and promoting thereby the formation of zones of metamorphism about it " (*loc. cit.*, p. 27).

I conclude that migmatisation is the prime cause of regional metamorphism.

Very early in these Meditations we considered certain aspects of the teachings of the master Lyell ; we may now return to them. Lyell's class of the Primary or Hypogene rocks consisted of two groups:

i. Stratified—such as gneiss, mica-schist, clay-slate.
ii. Unstratified—mainly granite or allied rocks.

The unstratified Primary rocks were called Plutonic. Lyell considered that the plutonic rocks were formed by igneous action at great depths, and he supported this view by arguments whose validity we have already examined (" Meditations on Granite : Part One," pp. 68-9). It is necessary to remember, however, that Lyell used plutonic as an attribute of a process as well as of a rock.

Plutonic action is so called by Lyell " because it appears to have been developed in those regions where plutonic rocks are generated, and under similar circumstances of pressure and depth in the earth " (*Elements*, 1st Edit., 1838, p. 18). When we look into the products of plutonic action we find some interesting matter. Thus, threads of granite are produced in sedimentary rocks by plutonic action (*Principles*, 4th Edit., 1835, vol. iv, p. 385) and larger bodies of granitic melt may also be a consequence. This plutonic influence has sometimes been " on so grand a scale (that) we must not consider that the strata have always assumed their crystallisation or altered texture in consequence of the proximity of granite, but rather that granite itself, as well as the altered strata, have derived their crystalline texture from plutonic agency " (*Elements*, 1st Edit., 1838, p. 19). In his early treatment of the metamorphic rocks, Lyell states :

> " The metamorphic theory does not require us to affirm that some contiguous mass of granite has been the altering power ; but merely that an action, existing in the interior of the earth at an unknown depth . . . . analogous to that exerted near intruding masses of granite, has, in the course of vast and indefinite periods, and when rising perhaps from a vast heated surface, reduced strata thousands of yards thick to a state of semifusion, so that on cooling they have become crystalline, like gneiss. Granite may have been another result of the same action in a higher state of intensity, by which a thorough fusion has been produced ; and in this manner the passage from granite into gneiss may be explained." (*Elements*, 1st Edit., 1838, p. 251.)

Essentially the same statement appears in the 12th Edition of the *Principles* 1875, p. 139, and is worth repeating :

> "The transmutation has been effected by the influence of subterranean heat acting under great pressure, and aided by thermal water or steam and other gases permeating the porous rocks, and giving rise to various chemical decompositions and new combinations, the whole of which action has been termed 'plutonic,' as expressing in one word all the modifying causes brought into play at great depths and under conditions never exemplified at the surface. *To this plutonic action the fusion of granite itself in the bowels of the earth as well as the development of the metamorphic texture in sedimentary strata may be attributed.*"

I have italicised the last sentence of this quotation to emphasize the Lyellian doctrine that plutonic action gave rise to both metamorphic and granitic rocks. The view expressed above that migmatisation and regional metamorphism are connected processes has thus a most honourable ancestry. I am of the opinion that in any scheme of rock-classification, the granitic and metamorphic rocks must be placed close together. This is a return to Lyell, and the combined group thus erected in his Primary or Hypogene group. It is regrettable that both these names are not readily acceptable : hypogene is one of a class of names which rings no bell with me, whilst primary has undesirable historical connotations. We have just seen that Lyell's plutonic action was responsible for both members of his Primary group : accordingly, I suggest that we re-employ plutonic in this sense. My first proposition is : *There is a Plutonic class of rocks which comprises the granitic and metamorphic.*

We may now return again to the French School for the source of the basis of our second class of rocks. It will be recalled that Élie de Beaumont clearly realised the existence of two fundamentally different groups of eruptive rocks, the one granitic and plutonic, the other basic, dominantly volcanic but including traps and serpentines. Michel-Lévy emphasized this distinction forty years later in his statement that he could not insist too strongly on the lack of either stratigraphical or petrological relation between the laccolites, the true volcanic chimneys with dykes and sills on the one hand, and the granitic masses on the other. Though the development of these views was a French achievement, it is well to remember as we have already seen that a similar contrast between volcanic rocks and Primary rocks was an early tenet of Lyell though, it is true, the master permitted himself later to swallow the igneous panacea. As I displayed last year (" Meditations on Granite : Part One," pp. 84-5), a modern presentation of the fundamental difference between the volcanic and the plutonic rocks is provided by the brilliant synthesis of W. Q. Kennedy (" Crustal layers and the origin of magmas," *Bull. Volc.*, Series II, Tome III, 1938, pp. 24-82). The two associations, volcanic and plutonic, erected by Kennedy, represent two distinct and apparently independent expressions of magmatic activity. The *volcanic association* is derived from a universal basaltic magma, and includes not only the effusive rocks but also all intrusions related to the volcanic activity and originating in the same magmatic source ; crystallisation-differentiation may be valid in producing the diversity of rocks among this association. As we have already noted above, Lyell accepted the great volcanic class of rocks—"undoubtedly recognised to be the products of fire, from the exact resemblances to those which have been produced in modern times by volcanoes " (*Principles*, 1833, vol. III, p. 10). Let us, sustained by Kennedy, return once more to Lyell. My second proposition is : *There is a Volcanic class of rocks.*

Where, now, stands this term igneous ? Bearing in mind that igneous means consolidated from a completely fluid melt, the magma, we are now obliged to restrict its use. The igneous rocks are the magmatic rocks, and these are dominantly the Volcanic class of our new grouping. This is another return to early Lyell—" volcanic, the products of igneous action " (*Elements*, 1st Edit., 1838, pp. 4-5). Some few of my Plutonic rocks are most likely magmatic and therefore igneous, but each example proposed must have careful study before the proposition is accepted. Enough damage has already been done by extending this term igneous too widely and too readily. If a rock can be demonstrated to have consolidated from a magma, it is an igneous rock, if not, not.

The remaining class of rocks proposed by Lyell, and not covered by my present suggestions, is his Aqueous—the sediments. It is a pity that we have no obvious name for them which matches with Volcanic and Plutonic—I propose with little hope of its adoption something along the lines of Neptunic. *The third class of rocks then is the Neptunic.*

We have now returned completely to Lyell. There are three great classes of rocks, Neptunic, Volcanic, Plutonic. There are a few odds-and-ends left over that can be tucked in at leisure. I present the following summary of the position :

THE THREE CLASSES OF ROCKS.[1]

1. **Neptunic.**—The sedimentary rocks, dominantly marine.
2. **Volcanic.**—Effusives and associated intrusives ; dominantly basic, magmatic, igneous ; non-orogenic ; comprises the orthodox volcanic rocks plus related minor intrusions, sills, laccolites, etc., as of gabbro, dolerite, andesite, trachyte, etc. ; crystallisation-differentiation may run in this class.
3. **Plutonic.**—Of two associated kinds, the metamorphic rocks, and the ultra-metamorphic, migmatitic, metasomatic, granitic rocks ; orogenic ; comprises the great granitic complexes, the gneisses and schists.

I submit these proposals for your consideration. Possibly the day of the heroic gesture is gone, and it better serves the prudent man to be quiet and canny. You may, however, be enticed by these remarks to permit a reorientation, maybe only a temporary one, of your outlook on rocks. If that happens, I am rewarded, if it does not happen, I acquiesce. As an Englishman, I recognise Sir Walter Raleigh's portrait of us : " If he cannot please by being himself, he is content not to please, and gives the matter no further thought." I leave it at that.

* * * * *

These Meditations, which have most pleasantly occupied my leisure for two years, are now before you. Once again I make a plea to the reader interested in the matter to consider both Parts together. Finally, I ask forgiveness of my friends at the Royal School of Mines who must have found me for the last two years a person of one topic of discussion. I regret that there is likely to be yet more to come—for in this matter, as in many others, the wisdom of Jesus the son of Sirach is true :

> " When a man thinketh he hath finished, then he is but at the beginning; and when he ceaseth, then shall he be in perplexity."

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[1] The Frontispiece displaying this classification has been kindly provided by Dr. Gilbert Wilson. For this, and for much kindly criticism, I tender my grateful thanks.

A NOTE ON TILTED FOLDS AND DIRECTION OF PITCH.

By JOHN CHALLINOR, M A., F.G.S.

[*Received 15th October, 1943.*]
[*Read in abstract, 31st March, 1944*]

DR. G. D. HOBSON, in a recent paper [**1***], has brought up the question of the "secondary tilt." In this connection it may be of some interest to consider the effect of tilting a fold or series of folds, with particular regard to the direction of pitch. This has a bearing on the reading of tectonic history from a geological map, where a uniformly dipping series overlies unconformably a folded and pitching series. Here one has in mind what may perhaps be called "regional pitch," as distinct from the local, incidental pitch which must occur, for instance, at the ends of all folds.

There are two methods of showing the effect of giving a secondary tilt to a rock-series ; one simple, but approximate (in certain circumstances), and the other more complicated, but accurate in all cases. The general case of an oblique tilt is alone considered here.

The first method consists in assuming that, on tilting, points on a stratum surface move vertically up or down, by amounts proportional to the distance from the axis of tilting. Figures 6 and 7 are examples to show the application of this method.

In Figure 6 the continuous lines are strike lines (stratum contours) for one bedding surface of a symmetrical, non-pitching anticline. Their levels are indicated by numbers and a scale of units would allow the dips to be measured. For instance, one unit might be 100 feet and the scale 10 units, or 1,000 feet, to the inch. The dot-and-dash line is the crest. The fold is then tilted about the line XY, and the plane of the tilt is also indicated by lines (dotted) analogous to strike lines ; and these are numbered in a similar way. The new strike lines for the same bedding surface are shown as broken lines, and the way they are obtained is obvious. The fold is now asymmetrical and pitching ; but the crest remains the same line as before. Figure 7 shows the same effect, starting with a fold already asymmetrical and pitching. The various sets of lines are similarly indicated, and the position of the crest is again seen to remain unchanged, though in the particular example chosen the pitch comes to be in the opposite direction. In both figures the fold is, for clearness, supposed to be sharply bent, and to have a constant dip on either limb.

The other, accurate, method is an application of Dr. Hobson's construction. He solved graphically the following problem : given the direction and amount of dip of a bedding plane which has been tilted in a known direction and to a known amount ; to find what the direction and amount of its dip was before tilting. The present construction involved, as its main part, the solution of the converse problem : a bedding plane having a given direction and amount of dip is tilted in a known direction and to a known amount ; to find the resulting direction and amount of dip.

The construction (Figure 8) is obviously based entirely on that described by Dr. Hobson ; but it shows one way in which his methods may be applied, and extended to touch on wider problems than might perhaps at first sight be supposed. The writer is greatly indebted to Dr. Hobson for verifying the construction and giving much valuable comment, and also for his readiness to allow him to make use of his ideas in this way.

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* For List of References, see p. 98

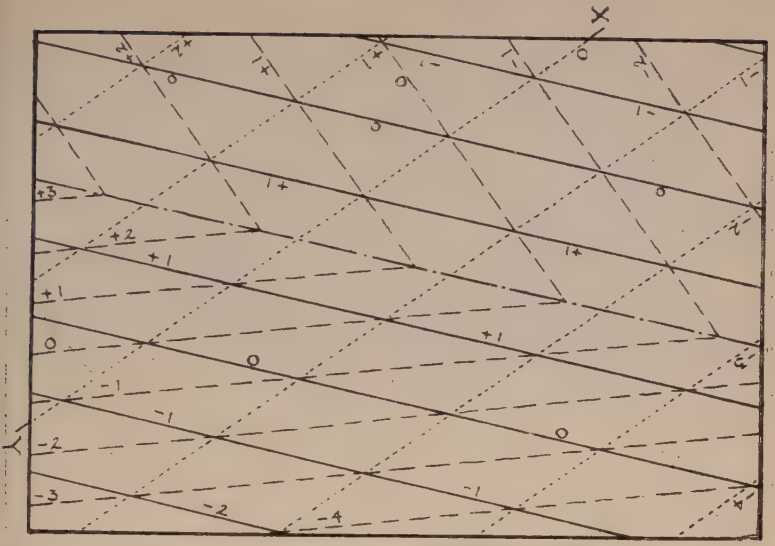

FIG. 6.—A SYMMETRICAL NON-PITCHING ANTICLINE CHANGED BY OBLIQUE TILTING IN TO AN ASYMMETRICAL PITCHING ANTICLINE.

The approximate construction results in the position of the crest being unaltered.

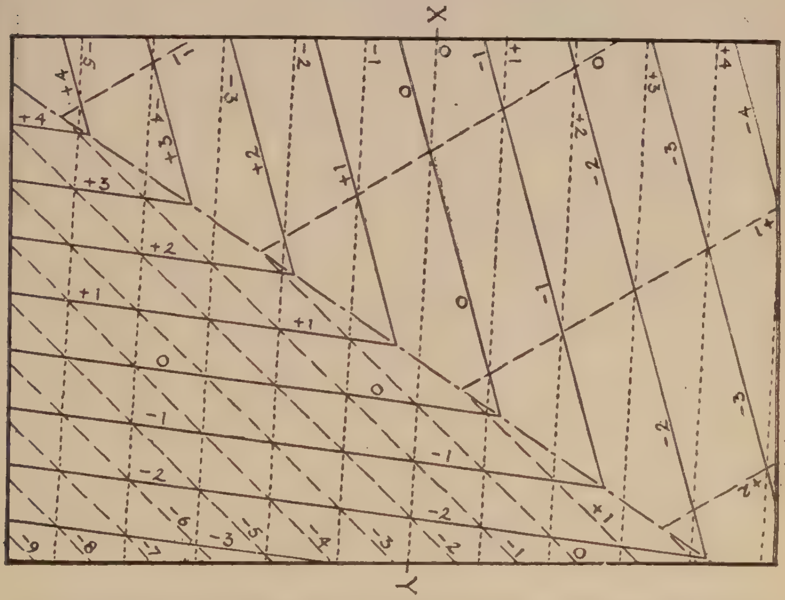

FIG. 7.—PLAN OF AN ASYMMETRICAL PITCHING ANTICLINE CHANGED IN FORM BY OBLIQUE TILTING.

The approximate construction results in the position of the crest being unaltered, but the pitch is changed to the opposite direction.

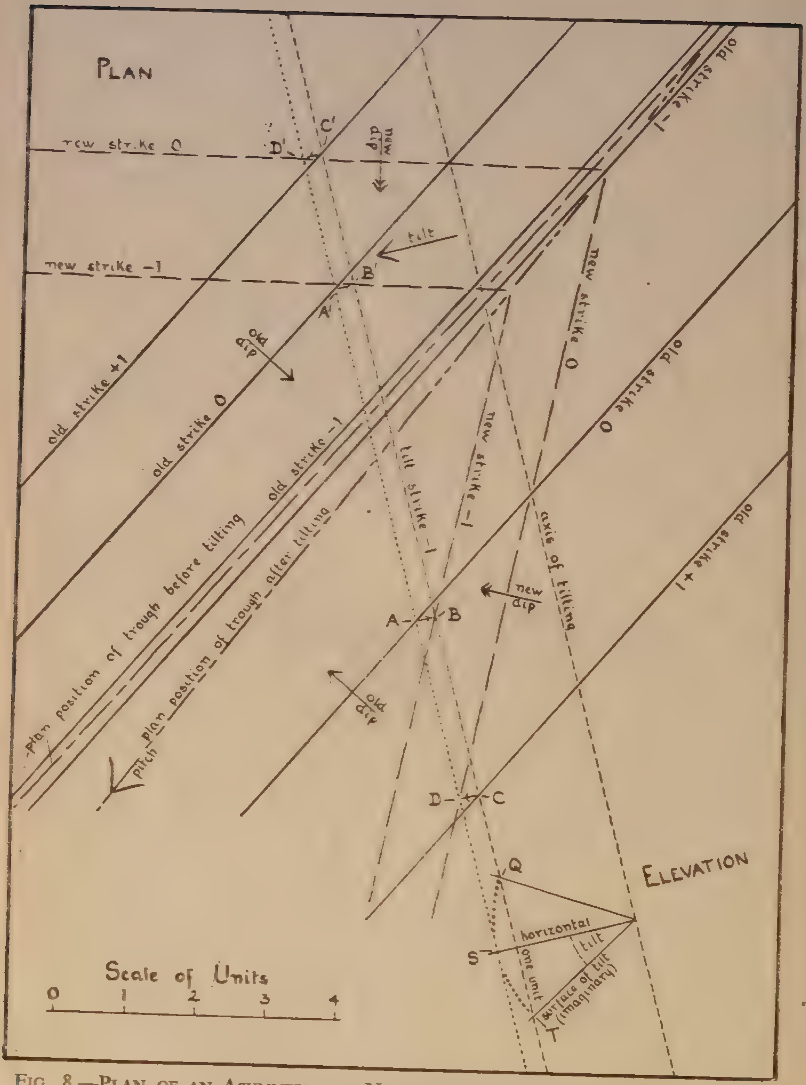

FIG. 8.—PLAN OF AN ASYMMETRICAL NON-PITCHING SYNCLINE CHANGED IN FORM BY OBLIQUE TILTING AND SHOWING THE RESULTING DIRECTION OF PITCH. ACCURATE CONSTRUCTION.

The figure is drawn and annotated so as to contain the explanation within itself. Mention of the following points may, however, permit it to be followed more readily :—

The particular example taken is a syncline with horizontal trough. In each limb the dip is constant, and the bedding surface is sharply bent. The plane of the paper is a horizontal surface at zero level. A line at zero level is selected as the axis of tilting. Only two or three strike lines are given for each surface. The line labelled " tilt strike—1 " is the projection, on to the horizontal zero surface (i.e. the plan-position), of a line, at a level of minus one unit, on the imaginary surface of tilt.

Any point on the bedding surface moves, on tilting, in a vertical plane through the arc of a circle subtending the angle of tilt at the axis. Thus, in the elevation, a point at S moves to T ; while, in plan, points at A and A^1 move to B and B^1 respectively. Similarly, in the elevation, a point at Q moves to S ; while, in plan, points at C and C^1 move to D and D^1.

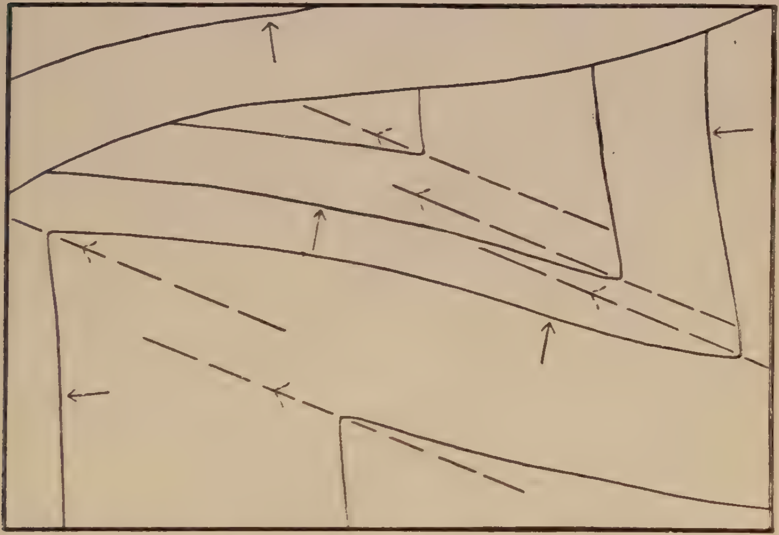

FIG. 9.—GEOLOGICAL SKETCH-MAP SHOWING PITCHING FOLDS OVERLAIN UNCONFORMABLY, IN ONE PART, BY A NEWER, UNIFORMLY DIPPING SERIES.

It will be seen that in this case the position of the trough does not remain unchanged (as it would if the approximate construction were applied), but moves slightly further away from the direction of tilt.

In the three constructions here given the fold is supposed not to be curved in any of its parts. It should therefore be noted that when the fold is not sharply bent, the new crest or trough will not be the same line on the bedding surface as the old one ; that is, the crest or trough will move on the fold during tilting. This complication requires working out, though the present argument is not likely to be materially affected. The terms " crest " and " trough " are here used in the sense proposed by Dr. E. S. Hills [2, p. 71].

It seems to be very generally assumed that the tilt causing the regional pitch in a series of pitching folds was given strictly in the direction of that pitch. However, it appears from these constructions that a fold tilted obliquely will acquire a pitch (or an added pitch) by no means in the direction of the tilt.

A sketch map of a piece of country, with a lower series of beds having a structure similar to that just produced, and with an upper series overlying them unconformably (in one part) with a dip similar to the tilt just given, might be something like that shown in Figure 9. It would be wrong to assume that the lower series had been tilted before the deposition of the upper series ; as the tilt given to the whole structure and expressed (presumably) in the dip of the upper beds, might be sufficient to account for the direction and amount of pitch of the lower beds. The approximate probable direction of this pitch is indicated by the broken lines.

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BASIC ENGLISH AND ITS USE IN GEOLOGY

(In Basic English).

By ALAN WOOD, Ph.D., F.G.S.

[*Received 29th October, 1943.*]
[*Read 4th December, 1943.*]

THE NEED FOR AN INTERNATIONAL LANGUAGE IN SCIENCE.

BETWEEN the years 1800—1900 it was possible for the man of science to get a good idea of what was being done in other countries. The number of workers in one branch of science was small, and almost all of them gave their results in one of three languages, French, German or English. At the present time the position is very different. The countries of the East take a greater part in the work of science. Though their output is small at present it is certainly increasing and will do so more quickly in the future. The best brains of the East now come to one of the chief European countries for training, but, in the future, when the level of science teaching in their countries becomes higher, this will no longer be necessary. It will be natural for teaching to go on in their languages, and accounts of new discoveries will be given in them. Such a tendency is certainly present, and if things went on in this way discoveries of the greatest value to other workers might be kept secret for years in a mist of words. Work done in one country would be done again in another and " International Science " would be only a name for a dead idea.

The time to do something is now. At present a great number of the special words used in science are international, because the important discoveries have been made in three or four countries, and the East has taken over the names while learning the sciences. The making of new words is not the right of any one country ; there is a natural tendency for the man who makes a discovery to make use of strange new names. Before the damage is done, while most of the words of science are still international, is the time to take this tendency in hand and to see that the development of science in the future is on the right lines.

It is frequently said that English, French and German are the three languages of science and attempts are made at international science meetings to give the results in one of these languages. Spanish has to be used, however, in meetings of American countries, and even if no other language was ever used, these three would be more than enough. Even for those whose natural language is one of them the time taken up by learning the others is great. In addition, the worker is not generally so happy with the other languages, and it is common for his reading to keep almost to the one. Proof that this is true even at the highest levels may readily be given.

For example, it may be said that certain branches of geology are international, in the sense that interest in them is not special to any one country. Such things as the origin of igneous rocks, the structure of the earth shells, and the theory of isostasy are of general interest. This being so, it is clear that writers on such questions will, in theory, give lists of earlier papers with the same distribution among the three languages, whatever the country of the writer That is to say, every expert will have taken note of all the important work which has been done before, inside the limits of the three international languages. Let us see if this is done.

In the last ten years two very noted writers have given an account of the structure of the earth. They give long lists of earlier papers, but the distribution of the papers among the three languages is very different. Professor B.

Gutenberg, a German, in " Geotektonische Hypothesen "[1] gives a list of 88 papers in German, 35 in English and 2 in French. On the other hand, the American, Dr. H. S. Washington, in " The Crust of the Earth and its Relation to the Interior "[2] gives a list of 126 papers in English, 30 in German and 9 in French.

Though these writers may be making observations on some branch of the question which has had special attention in their country, the papers are so wide in their outlook that this will have had little effect. In general there is no doubt that the reading of these writers has been given a special direction because a certain country was, by chance, their birthplace. The reasons for this limited reading are clear. They are, firstly, that it is hard to go through a paper in a strange language quickly, to take note of any special points of interest. Probably an English reader takes as long to go through one German paper as four English ones. Secondly, in a number of places it is hard to get all the desired papers from other countries.

However this may be, the fact that international reading so clearly does not take place even inside the limits of these three languages makes it certain that if writing went on in almost every language a number of discoveries which would be most important to other workers would go unnoted for years.

The international distribution of " abstracts," though better than nothing, is not enough, for a small, seemingly unimportant, part of a paper may be a pointer to some law of great general value when gone over by a new mind, coming to it from a different angle.

The need, then, is for some international language which may be used as a second language in all the countries of the earth, and which will become the common instrument for the exchange of views among men of science. It will not have to be hard to become expert in such a language, or its learning will take more time than the common man is able to give. In addition, it will have to be clear and have fixed rules, or changes will be made by persons without authority and it will no longer be the same language for all. Lastly, the structure of the language has to be such that it may be used as a framework for those words which are now international for the purposes of science. Basic English is such a language, and the greatest chance of a general change will come straight after the war, when the design for a new way of living will be worked out.

WHAT BASIC ENGLISH IS.

There are well over 200,000 words in the English language, while Basic English has 850 for general use. It is interesting to see how this small selection has been made.

The English language is made up to a great degree of words whose special purpose is that of producing a feeling in the reader by the connections they have in his mind. Political ideas are generally " put across " by the use of such words, but they take an important part in the talk and writing of common men. Such words are in fact shorthand words for complex ideas. In Basic English such words are not present. They are broken up into a number of simple words which give the same idea, and this in itself makes it possible to get on with a much smaller number of different words. In addition, words which have almost the same sense as some other word in the list are taken out. Examples are 'large,' 'big,' 'huge,' 'immense,' 'gigantic,' 'tremendous' and so on, whose sense is given by the word 'great' together with such a word as 'very' when necessary.

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[1] *Handbuch der Geophysik*, 3, p. 442, Borntraeger, Berlin.

[2] *Physics of the Earth*, vii, p. 91. McGraw Hill, New York.

The same shorthand tendency of English is seen in its ‘ verbs ’ which are frequently words for complex ideas. Again these may be broken up into a number of simpler words and in fact there are only 18 ‘ verbs ’ in Basic. For example ‘ to excavate ’ (a drain) would be to get the drain up, and to excavate (a fossil) would be to get the fossil clear of the rock. In the same way ‘ to visualise ’ is to see in the mind’s eye, and ‘ to verify ’ is to make certain that something is true. Again this makes Basic much more simple, for “ verbs ” with their different forms are specially hard for the learner, and the number of words is made much smaller. It might seem that Basic would be a very roundabout way of saying things, but this is not so. Nine times out of ten those words which have special connections or shades of sense are used by chance. Only a small number of great writers make use of the right word in the right place. The work of most other writers may be put into Basic without any marked change in the sense, and without making it much longer. The paper which comes after this took up almost the same space in Basic as in wider English, the Basic account being in fact some lines shorter.

Basic English, then, is an attempt to keep down the number of words used as much as possible, and to make the rules for their use simple, so that there will be less trouble in learning the language. There are only 850 words in Basic English for everyday purposes of which 18 are ‘ verbs.’ In addition, the English names of numbers, days of the week and months of the year are used and any truly international words. A list of 100 general science words is given for use when writing about any science, as well as a long list of international ones, and in addition every branch of science may have a special list of 50. The special words for geology are given later (p. 102). A number of endings are made use of as in wider English. Such are the ‘ s ’ form for number (together with a small number of forms which are not regular—foot, feet, leaf, leaves), the addition of ‘ ed,’ ‘ -er,’ ‘ -ing ’ to ‘ nouns ’ (design, designer, designing, designed), and ‘ -ly ’ to ‘ adjectives ’ to form ‘ adverbs.’ The number of words which may be used is increased in this way, while learning is not made much harder. A knowledge has to be got of the forms for comparison, the forms of ‘ pronouns ’ and the forms of ‘ verbs.’ The last thing is to get an idea of the expansions of sense which go with most words. Here again there are fixed limits. In wider English the same word may have a number of senses and shades of sense which frequently have little or no clear connection with one another. Take the word ‘ to bear,’ which may be used of babies, with the sense ‘ give birth to,’ of pain, to put up with pain, of news, to take the news somewhere, and of behaviour, as in “ he bore himself well.” Again, his ‘ proud bearing ’ is as different from his ‘ lost bearings ’ as a “ bear-ring ” with fighting animals is from a ring ‘ borne ’ on the finger. Such words are a danger to those learning English. The Basic uses are limited to a selection of those which have a clear connection with the root sense. So the word ‘ light ’ may not be used of weight, or the word ‘ even ’ for ‘ level ’ and a ‘ ring ’ has nothing to do with a bell, or a ‘ start ’ with a jump.

It will be seen that Basic English is as simple as possible, cutting down the number of words which are necessary as well as the rules for their use. Anything simpler becomes ‘ Pidgin ’ English, while every word more is another weight on the memory of the learner.

BASIC AND ESPERANTO

The persons who give support to one or other of the made-up languages say that no language in current use may be made international because all are so hard for the learner. The rules are complex, and the number of ‘ strong verbs ’ are an ever present trouble. We have seen how these points are overcome in Basic. In addition, it is said that the country whose language was made international would have a better chance than the others, in trade for example, and that other nations, fearing this, would take care that no living language was made use of for the international exchange of knowledge and ideas. This is taking a very low view of men's feelings, and even if these persons are right it is no argument against Basic, for the English themselves would have to take the trouble of learning Basic before they were in a position to make use of it. In fact, in some ways an Englishman might even have more trouble in learning to say things without error in Basic than a man of another country. Again, it takes such a short time to get a knowledge of Basic that this point becomes less important.

Esperanto is a made-up language based on six European languages. It seems that learning Esperanto is simple for a European, but this does not seem to be so for those whose natural language is very different in structure. Asiatics and Africans do not seem to be deeply interested in it.

Lastly it is clear that the learning of Basic is a step in the learning of wider English. All the rules and words which have been given are part of the English language, and the learner may go on learning new words whenever he has the need for them. Esperanto and other such languages do not make one free of such a storehouse of great writing, however expert one may become in their use.

BASIC AND GEOLOGY.

We are in the happy position of having a great number of international words in current use. Geology is such a young science, and the most noted geologists have so frequently been men whose language was English that English words make a great part of this international list. It is clear that the learning of these words is the learning of Geology, not of language as such, and their use does not make the learning of Basic harder for those whose natural language is not English. Such words as ' plutonic ' or ' porphyritic ' have to be got into the heads of Englishmen, Americans and Asiatics equally, and would have to be part of any international language.

However, a number of the more common words are not international. This is so in every science, for words taken by the early workers from everyday language will be different in every tongue. Fifty special words which are not international may be used when writing about Geology in Basic English. They are : Accessory, Birefringence, Cast, Cave, Clay, Cleavage, Contour, Desert, Dip, Drift, Dyke, Erosion, Eruption, Extinction, Fan, Fault, Flint, Flood, Flow, Foliation, Fracture, Glacier, Gravel, Ground, Hill, Igneous, Inclusion, Intercept, Interpenetration, Intrusion, Lake, Limestone, Mud, Ore, Outcrop, Outlier, Overlap, Plain, Scarp, Schist, Sedimentary, Shale, Shore, Sill, Slate, Strike, Texture, Twin, Unconformity, Valley.

Lastly, there is the question of coming to a decision as to which words are truly international. The present writer, naturally, has not the necessary knowledge or authority to do this. Only a committee of experts in every branch of Geology would be able to make these delicate decisions. It will be seen in the future if it is possible for such committees to be formed. The need is certainly to make our special language more simple so that the reading of papers on Geology may be a pleasure to everyone. A general view of the different branches of Geology, to see how far their language is international at present, may now be given.

(a) Physical Geology.

This is clearly one of the most complex branches of geology from the present point of view. Every language has its special names for the different parts of the everyday countryside. These are so much a part of the very thought of the nation that it is hard to make them give place to others. The way in which the names 'Cwm,' 'Coombe' and 'Corrie' are kept for certain dry valleys is an example of how one may have an unreasoning feeling for a name simply because one is used to it. If as in this example it is not possible to get agreement among the geologists of one nation it is not probable that a decision will ever be made on the value of names given by different nations. Any words may, however, be used in the writing of Basic, if a clear account of their sense is given in Basic at the same time. If, for example, it is necessary to put the word 'Corrie' into a paper it is no trouble to say "these valleys which are cut into the Chalk hills and whose sharply sloping sides make almost half a circle round their flat floors are given the name *corries* by A. J. Bull." This is not a waste of paper, such an account gives a much clearer picture to the mind than does the use of the word 'corrie' with its uncertain values. Though it is probably not possible to get the same names used everywhere in Physical Geology, with its complex processes and unending range of land forms, the use of such outline accounts of any words which are not Basic will make the chance of error much smaller.

(b) Petrology, Mineralogy, Crystallography.

These sciences have a long list of international words. However, the names of the commoner minerals are not the same everywhere. They were taken from the language of mining men, and together with most of the common mining words are different in almost every country. A paper by Dr. L. J. Spencer[1] gives a very clear idea of what has to be overcome in any attempt to get international agreement on the names in use in the last two sciences. Different names for the same thing, even the same name for different things, different ways of giving the symbols for the crystal faces and the names of the crystal systems, make a complex twisted network which seems as if it will never get straight again. One comes across the same trouble in Petrology as may be seen from the ever-increasing number of rock names. In these sciences, however, the things which are worked with are seen as separate bodies with material existence, while those things which take all the attention of physical geologists are in comparison complex and unclear in outline. The outcome of this is that chemical formulae may be used together with the mineral names, and it makes possible the healthy tendency of giving a list of the chief minerals in the rock name. This will go far in the direction of making these sciences international. In addition a short account of the sense of any word not in Basic may be given, as in Physical Geology, and the same points may be made in support of this.

It is quite simple to put the language of Petrology into Basic as may be seen from this example.[2] Professor Read says: "The rock varies in degree of foliation, from slightly deformed porphyritic granite to plane-foliated ribboned pink and grey rock. In slices the felspar phenocrysts are orthoclase with microclinic patches, microperthite and acid plagioclase. The last named is filled with tiny muscovites and epidotes. The margins of the felspars are usually rounded or embayed, while in almost all slices the crystals are seen to be broken and displaced, the fractures being healed by quartz." The Basic account might be: "Different degrees of foliation are seen, from little changed porphyritic granite to a rock with parallel light red and grey bands. In section, the felspar phenocrysts are orthoclase with microcline inclusions, microperthite and acid plagioclase. The last is full of small muscovites and epidotes. The edges of the felspars commonly have curving outlines, inlets being sometimes seen, while in almost all sections the crystals are broken, the parts being out of position and joined together by quartz."

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[1] "International Agreement in Mineralogical and Crystallographical Nomenclature." *Mineralog. Mag.*, 1925, vol. xx, p. 353.

[2] Read, H. H. "The Metamorphic Geology of Unst in the Shetland Islands," *Quart. Journ Geol. Soc., London*, vol. xc, 1934, p. 677.

(c) Palaeontology and Stratigraphy.

The use of the Linnean System and the "law of priority" have made much of Palaeontology international. Only the names for the different parts of shells and bones are not fixed—clearly because the names for these parts come from the language of common men. The names of parts of animals not now living are much more international, because they were given by men of science to things which were never part of common knowledge.

Palaeontological accounts go well into Basic, as may be seen from the paper which comes after this one. Another example, which at first seems as if it would be hard to put into Basic, may be taken from the works of Spath: "It has been seen that the incontrovertible evidence of stratigraphy does not favour this view that there was a persistent unspecialised, ancestral, capricorn stock, giving rise to a number of progressive branches that, after a meteoric career, disappeared one by one as a result of over specialisation. On the contrary; the tendency to close coiling which resulted in the early, suturally specialised sphaerocones initiated a stream of evolution which at its acme showed rapid differentiation and great plasticity, resulting in at least one unsuccessful experiment (Beaniceras); but the specialized, ancestral stock persisted, and even the simplified capricorn branches, in spite of their far greater abundance in individuals, were doomed to extinction before the rarer sphaerocones (Liparoceras) disappeared."[1] The Basic account might be: "It has been seen that the undoubted facts of stratigraphy do not give support to the view that there was an unchanging, simple group of capricorn ammonites, giving off a number of increasingly complex branches, which, after a quick evolution, went out of existence one by one because their adjustment to outside conditions was so complete. Quite the opposite: the same tendency to tight growth which gave the early sphaerocones with their complex sutures put into motion a current of evolution which at its quickest was made up of a number of different readily changing forms, of which one at least came to nothing (Beaniceras); but the complex early group kept on without change, and even the simpler capricorn branches, though they were present in much greater numbers, were marked out for destruction before the sphaerocones (Liparoceras) came to an end."[2]

The greater number of the chief names used in Stratigraphy are international. Though the names of the divisions lower than the Systems are frequently not in international use, this is caused by the way in which the facies of the beds becomes different from point to point and so it is a necessary outcome of the special qualities of the science itself. The use of the names of small country places for divisions of the lowest degree is necessary and will not get in the way of the international distribution of knowledge. However the use of a system of lettering taken from the first letter of the name of a special fossil seems to the present writer to have much to be said for it. The letters and the fossil names are international and the use of such a name as Kinderscoutian, newly put forward by Dr. R. G. S. Hudson, instead of R_1, is a step back from this point of view.

GENERAL SUGGESTIONS.

It will have been seen that while a great number of words used in Geology are international, a number are not. The use of Basic seems to be the best way of getting free from troubles and arguments coming from the use of words whose sense is not clear. The fact that new words, or older words not in Basic, may only be used when their sense is made clear seems to make certain that anyone with a knowledge of the science will be able to go through any paper with profit. If the new name, or the old one, is truly necessary it will by degrees come into use and will become part of the international language for the science. This idea, so simple in theory, may give trouble in use. Who is to say which is the best name for a certain thing? The hope for the future—the great Idea—is to have a truly international language of science, in which there will be only one name for one thing and its sense will be clear to all. The suggestion is here made that it would be a good rule to give first place to the first use of a word in a Basic paper with a clear account of its sense and it would then become the form used by everyone. If the word is not necessary it will come to a natural end. The rule of taking the first name put forward has done what it was designed to do in Palaeontology and Zoology, even though the early work was done without attention to the needs of later workers. If writers of Basic science papers were conscious that any uncertain step made its mark on the language, and that they were writing for those coming after, more care might be taken. Writers would be conscious that it was necessary to make use of the best words, and the outcome might well be a better language than any now in existence. From this point of view Basic is a new language, and the time when such a language comes into existence is the time to give thought to the future, for no man is able to say how far the use of Basic may go in time or space.

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[1] Spath, L. F. (1938). *The Ammonites of the Liassic family Liparoceratidae*. British Museum (N.H.), p. 27.

[2] The words "over specialization" may have some other sense than that given to them, but it is not clear in what way they are to be taken. In addition two words which are probably not international are made use of ('capricorn' and 'sutures'), but though it would be simple to give their sense in Basic, it would make comparison between the two accounts less simple, without any special profit.

Basic will have its best chance in the first years after the war. The nations of the earth will be ready to get a knowledge of English and Basic is the first step in this direction. In the "Interim report of the British Association Committee on post-war Education"[1] attention was given to the question of an international language, and it was said that men and women at our Universities might well give some time to the learning of such a language. Basic seemed to be right for this purpose, but the system would have to be looked into in detail. The Prime Minister has said at Harvard that some language such as Basic English would be of great use, and a decision is being made as to its possible value after the war.

In the end our business as Geologists is the writing of more and better papers, so that a knowledge of Basic, if Basic gets support, will be necessary to everyone. This paper, and the one which comes after, are given in the hope that they may be of some little help in this direction.

NOTE.—For more details of Basic English see "Basic English," "The A.B.C. of Basic English," "The Basic Words" and "Basic for Science," all by C. K. Ogden, and "Basic for Geology" by P. M. Rossiter (Kegan Paul Ltd., London). In addition the "General Basic English Dictionary" (Evans Bros., London), giving the sense of over 20,000 words in Basic English, is of great value to anyone making a start with Basic.

DISCUSSION

(Not in Basic English).

MR. A. WRIGLEY thought that the use of Basic English might greatly improve many scientific papers where a lack of clear thought or of really original matter is too often concealed by a fog of pretentious words, to an extent which requires a new Pope to write another Dunciad. It is tempting to use simple English words like *tip* for *apex*, *beak* for *rostrum*, *front* and *rear* for *anterior* and *posterior* until one remembers that the longer words of Latin origin will more readily be understood by most European readers. Although Basic is not intended to replace standard English, there is a danger that it may injure our native tongue, in the analogy of Gresham's law of an inferior coinage supplanting good money. If, as many philosophers maintain, we think only in and by words, an important question arises. The ambiguity of terms may be amended by their definition, but our language, especially in its verbs with their ascription of power, has a concealed skeleton which we inherit from a very distant past, and the adoption of Basic will require or will condition a new sort of thinking.

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[1] *Advancement of Science*, 1942, p. 256.

The Author, in reply, agreed with Mr. Wrigley that the writing of papers in Basic English was a very good test of clarity of thought. He was not competent to discuss the philosophical problems involved. In order to clear up some misconceptions which had arisen, he wished to point out that we could not expect foreigners to write or speak Basic unless we ourselves were prepared to write papers intended for an international audience in Basic, and were able to carry on a conversation within the limits of the Basic vocabulary when the need arose. If we, the English people, were prepared to do this, the spread of Basic might well be rapid, with great advantage to the world in general.

ORGANS OF REPRODUCTION IN THE SOLENOPORACEAE

An example of writing in Basic English.

By ALAN WOOD, Ph.D., F.G.S.

[Received 29th October, 1943.]
[Read 4th December, 1943.]

FROM as far back as 1894, when Brown made the first suggestion that *Solenopora* might be an alga, almost all writers who have done work on this genus have seen bodies which they took to be sporangia in the species they had before them. These structures were strangely different in form. Pia, in 1927, said that they were all wrong in their interpretations, and he made the new family Solenoporaceae, whose special point was that the organs of reproduction would not be seen in the fossil condition. It seemed probable to him that these bodies were on the surface, and the calcified parts[1] under them, so that by the time the calcified cell walls had got to this higher level the sporangia or other organs of reproduction would be gone. Not till the late Jurassic or Cretaceous did the evolution of more complex forms from these early genera take place. Even after this statement by one of the first authorities records of sporangia still were made by a number of writers. One of the most interesting papers is that of Opik and Thomson (1933), who gave an account of conceptacles in the type-species *S. spongioides* Dybowski. In 1940 Pia himself said that sporangia were present in a Jurassic *Solenopora* from Australia, though he did not say what effect this discovery would have on the family Solenoporaceae. The present writer has made the discovery of bodies like the conceptacles of Opik and Thomson in *S. gracilis* Garwood and Goodyear of the Woolhope Limestone, and here gives a new theory as to their origin. All other records of organs of reproduction in *Solenopora* and its relations are gone into with care.

The first statement that sporangia had been seen in *Solenopora* was made by Brown (1894), who gave pictures of these bodies in the new forms, *S. jurassica* and *S. compacta* var *trentonensis*.[2]

In the first species (Fig. 10a) spaces of a rounded form were seen and said to be conceptacles, while other cells of star-like arrangement might be regular cells round the opening of a conceptacle. The Ordovician species had cells of greater size among the normal sort (Fig. 10b). Rothpletz saw specimens of *S. jurassica* (1908, p. 11) and said that the spaces seen by Brown were probably chance holes, and the star-like cells places where a number of cells had been cut parallel with their length, while the cells about them had been cut across it. To get proof that they were sporangia it would be necessary to see thin sections of them cut in two directions. He said that such sections had been made from specimens of a new species *S. gothlandica* (Fig. 10c). The sporangia in this species were of the sort seen in *Archaeolithothamnion*, placed separately in the perithallium, not in groups. They were swellings at the top of normal cells, and were at different levels in the thallus, not at the same level as in *Archaeolithothamnion*. The fact that these bodies had only poorly calcified walls was looked on as natural if they were sporangia. In a later paper (1913) they were pictured again and were used in a detailed new account of the genus. Garwood and Goodyear (1919) saw the same long clear spaces in sections of their new species *S. gracilis*, which they said was probably a near relation of *S. gothlandica*. The spaces were named 'pseudosporangia' by these writers,

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[1] The parts turned into $CaCO_3$

[2] This variety may be well based; the work of Fritz (1941) has made it clear that a number of forms are present in the Trenton limestone, from which the type of Billings' species *S. compacta* came.

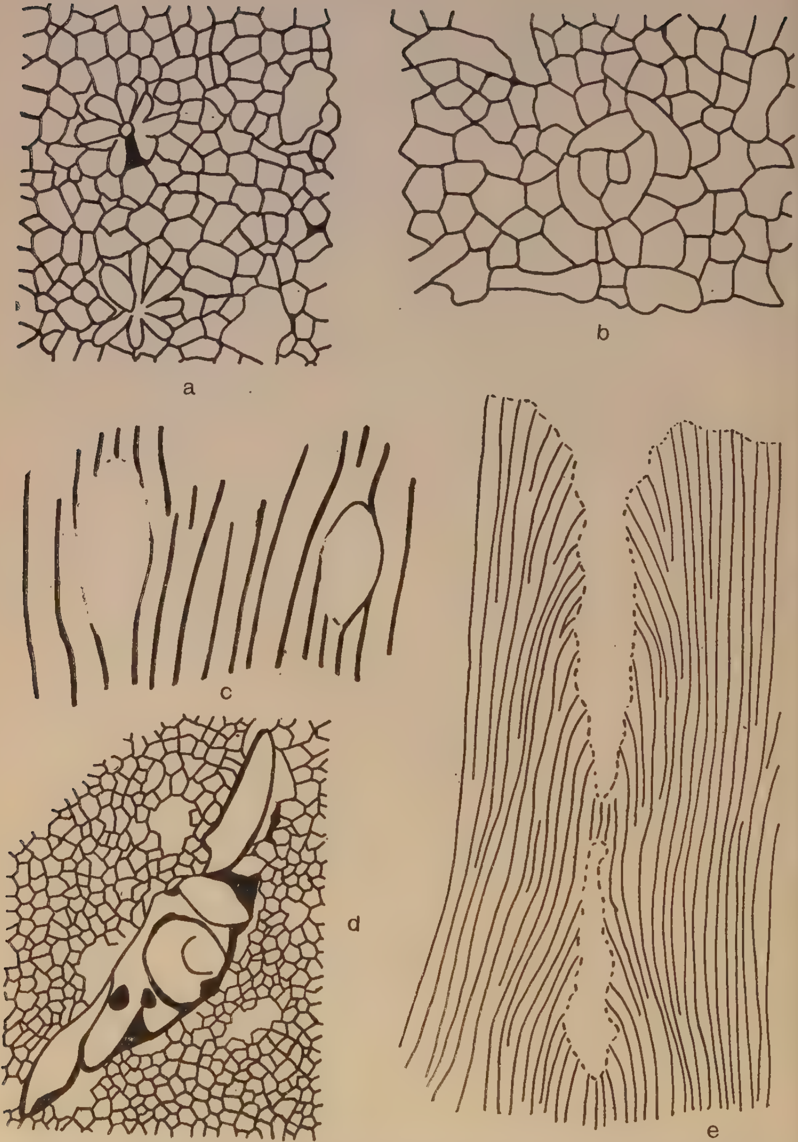

FIG. 10.—Bodies taken to be sporangia in species of the *Solenoporaceae* a. *Solenopora jurassica* (Brown, 1894). b. *S. compacta* var. *trentonensis* (Brown, 1894). c. *S. gothlandica* (Rothpletz, 1908). , d. *Parachaetetes megalocytus* (Pia, 1940). e. *S. spongioides* (Opik and Thomson, 1933).

who said that they were probably not sporangia. They seemed to be formed by solution of parts of the cell-walls, because the walls were broken at these points and were not curved round the spaces. At about the same time Lemoine (1918) was writing that the spaces seen by Rothpletz were quite probably sporangia, and that they were of the same form as those of *Archaeolithothamnion*.

Lemoine (1927), working with new specimens of *S. jurassica*, made the discovery of star-like groupings clearly like those first seen by Brown, but gave no opinion as to their true origin. In 1929 Peterhans gave a picture of some spaces seen in *Pseudochaetetes champagnensis*. They were all at the same level in the thallus, but were not regular in form. They were said to be probably conceptacles. The suggestion was made that the different arrangements seen in *Solenopora gothlandica* and *Pseudochaetetes champagnensis* might be a point of division between the two genera. The discovery of long cells like those first noted by Brown in *S. compacta trentonensis* was made by Pfender (1930) in a species of *Solenopora* from the Jurassic of the south of France. This new species seemed to be like Palaeozoic forms in a number of other points.

Opik and Thomson (1933) made sections of specimens of the genotype *S. spongioides* and saw that there was a strange arrangement of the cells round long spaces in the thallus (Fig. 10e). The spaces were certainly present in the living plant for the cells got wider and bent over when they came near them. The spaces were round in section and seemed to be broken at times by the joining of cells across from side to side. They were said to be conceptacles. Small narrow holes had been made in the outer surface of the alga after death, and it was said that these might give an idea of the way in which the sporangia of Rothpletz had been formed.

Star-like groupings of cells were seen by Maslov (1935) in the new form *Solenophyllum palaeozoicum*, as well as groups of round cells on the surface of the alga. He said the first sort might be the female conceptacles, and the others, which were less calcified, and not so regular, might be antheridia. Pia (1937) gave an account of the Upper Palaeozoic algae and said that the observations which had been made were no proof of the existence of sporangia, and he was not able to give up the family Solenoporaceae. The structures which Opik and Thomson had seen might well be caused by the growth of soft-bodied organisms on the surface of the alga. There was then a discussion of Maslov's work, and the suggestion was made that the star-like groups might be places where sporangia had been fixed to the surface, and had come off before being covered by calcified layers. In the same year Zuffardi-Comerci saw small irregular spaces in *Solenopora parvula* Z-C., but was not able to come to any decision about their true origin.

Oakley (1941) gave an account of the relations of the group. He said that Solenopora was most probably an alga, that specialization of the cells was in a very early stage, and its conceptacles might have been formed by cells of a greater size or cells which had been joined together. The star-like groups might well be a stage in the evolution of true conceptacles.

Lastly, Pia himself, in an account of a new species of *Solenopora* from Australia, gave a picture of cells greater than the normal size which (Fig. 10d) were placed in groups or by themselves in the thallus. They were near the dark bands—places where the cell-walls were thicker—and their walls were exactly the same as those of the normal cells. He came to the decision that they were probably some sort of early sporangia.

THE VALUE OF THESE EARLIER RECORDS

It will be seen that the bodies looked on by these writers as having a connection with reproduction are very different in form. The sort of structures present in living genera are clearly important in coming to a decision as to the value of these fossil records. Reproduction in the Corallinaceae may be by sex processes or without them, in the one case by carpospores and in the other by sporangia. All the organs of reproduction are formed in spaces in the thallus, named conceptacles, so that there may be male and female conceptacles and conceptacles housing sporangia. They may be of different sizes or the same size but reproduction by sporangia is most common. In *Archaeolithothamnion* every sporangium is in a separate conceptacle, and in *Lithothamnion*, though there are a number of sporangia in every conceptacle they are separated from one another. Only in *Lithophyllum* is there no separating tissue in the conceptacles. These forms come to the fertile condition somewhat suddenly and so the arrangement of the conceptacles is parallel to the surface, or to an earlier surface, an important point when judging the value of records of fossil sporangia. Every conceptacle in such a line has a tendency to be like the others in form.

A number of structures have been taken to be sporangia by these writers. They may be put into different groups.

(a) Cells without regular form.

It is frequently hard when working with fossil algae to be certain if a space seen in the thin section is truly part of the plant. This difficulty is caused in part by the very small size of the grains of calcite forming the walls, and the resulting fact that the walls are only feebly transparent, and in part by crystallization of parts of the thallus after death. Our only way of judging these spaces is by comparison with present day specimens —firstly are they regular in size and form, and secondly do they have some regular arrangement parallel to the growth lines. The fact that certain structures have been seen only once might be used as an argument against their being conceptacles, but for the fact that only a small number of sections have been cut of some species, and that we have no record of the fertile condition of some present day forms. Judged by these two tests the cells of great size which are sometimes seen are not conceptacles ; though the specimen of which Pfender gave a picture had a number of spaces parallel to a growth-line they were not at all regular in form. The specimen pictured on our Plate 5, Fig. 1 gives an idea of the surprising structures which may be present in the surface layers of an alga without having any connection with its way of living.

(b) Star-like groups of cells.

Five different explanations have been given for this arrangement of cells. They were an arrangement of cells round the opening of a conceptacle (Brown), normal cells cut at an angle (Rothpletz), the female conceptacle itself (Maslov), the supporting cells under a sporangium fixed to the surface (Pia), or grouped conceptacles (Oakley). The fact that these structures have not been seen in sections cut down the length of the cells may be noted, and this makes one uncertain about the existence of these bodies.

Though it is an undoubted fact that the eye has a tendency to see designs in any arrangement of things which have a general similarity of form, without all being exactly the same, this is probably not the complete explanation. But, till sections cut in the right way make clear the exact structure of these cell-groups, no discussion of their purpose has any value.

The great cells seen by Pia (1940) are different from the common type of grouped cells, and, judging from the figure given, have no necessary connection with reproduction. An equally good explanation seems to be that they are part of some animal fixed to the surface which was covered by a later growth of the alga.

(c) The conceptacles of Opik and Thomson.

Pia has said that this structure may have been caused by some soft-bodied organism which was on the surface of the alga. The same structures were seen a short time back by the writer in *Solenopora gracilis* from the Woolhope Limestone of Old Radnor (Plate 5A, 6A and B). It is clear that the special points seen in the Esthonian specimens are present, and, in addition, the structures are placed parallel to the growth-lines. As was noted by Opik and Thomson, the fact that the cells are turned to the spaces and get greater in size as they get nearer to them is proof that the spaces were there when the plant was living. But, though, in the specimen under discussion, there is no great difference in the form of these bodies, in others a complete range may be seen between regular forms and spaces which are not regular at all. The space figured by Garwood and Goodyear (1919, Plate VI, Fig. 2) has the same qualities as the present structures, and the writers had seen that the cells got greater in size as they got nearer to the strangely formed space. To make such structures as those seen in Plate 6A some soft-bodied animal on the surface of the alga may have undergone a quick disappearance after death, or possibly some animal took a bite out of the alga at this point, Whichever took place the outcome would be the same, a certain part of the thallus would come to an end suddenly and the growth of the other part would go on. The cells round the dead place would become turned in to take the place of the dead ones, and in so doing they would get greater in size, because they would be freed from the growth pressure of the cells about them. In their turn the cells farther from the space would be freed from growth-pressure on one side and would become turned in. For this reason the limiting line between normal cells and those of greater size is at an angle to the axis of the complete structure. Lastly, it may be noted that the inner cells, which were bent most strongly, were shaded by the outer ones and for this reason they did not go on living long enough to take up the complete space. Though the structures in *S. gracilis* are not exactly the same as those in *S. spongioides*, the agreement is near enough to make it probable that the explanation of the 'conceptacles' is the same.[1]

(d) The sporangia of Rothpletz.

It has to be said that, judging from Rothpletz's pictures, the calcified walls in his Plate 4, Fig. 5 (1908) are uncommon. Almost all the 'sporangia' are without walls. This is again the case with the 'pseudosporangia' of *S. gracilis* and there is little doubt that these bodies are the same in the two Silurian species.

A new interpretation of these bodies in *S. gracilis*, with the help of much new material, as well as the types[2] has made certain new features clear.

Specimens with these structures do not seem to be very common in my material, but when they are present they are in great numbers. Smaller bodies of the same structure are present (Plate 5B), and there is a complete size range between these and the normal sort. The relations with the cell walls are important. The cell walls seem to be formed of algal dust, and the calcite in the cell spaces is more crystalline, but is still made of very small grains. The 'sporangial' spaces have calcite of even greater grain size in them, and there is no special wall round them. The cell walls go straight into the base and top of the 'sporangial' space, and this, when it gets wider, may come against the side walls and frequently seems to have taken them into solution. These seem to be the points which had been noted by Garwood and Goodyear and which made them say that the ' pseudosporangia ' had been formed by solution. The point is, what sort of solution ? Solution acting after the death of the plant would not make bodies of this sort, for no paths are seen by which liquid came to take material into solution, and there is no reason for solution to have acted on such limited parts of the thallus. If these bodies were formed by solution or by animals in the life-time of the alga, and later were covered by new growth, then it is not possible to see why the threads on top seem to come straight out of the ' sporangium ' and are not turned in as in *S. spongioides* and in other specimens of *S gracilis.* We have then only solution inside the plant itself as a possible explanation—a solution of part of the inside by living tissue after the cells round about had been formed. This is the way in which the growth of the conceptacles of the Lithothamniaceae takes place. They get greater in size and take in the cells about them. A rough picture of *Archaeolithothamnion lugeoni* Pfender (after Rao and Pia, 1936) will make this point clear (Text Fig. 11) and will give an idea of how near the structures in the two genera are to one other. Though these facts give support to the theory that the spaces in *S. gracilis* and *S. gothlandica* are sporangial in origin, there are still some difficulties in the way. The first is the different size of the bodies, the second is their arrangement without relation to the growth-lines. They may well be sporangia, but this is still uncertain.

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[1] It may be said that the fact that these two species have the same reaction, as far as we are able to make out, to the same cause, does give one the idea that their physical structure was the same. It had been doubted if *S. spongiodes* (the genotype of *Solenopora*) was an alga because cross walls (and so cellular structure) were not seen, while *S. gracilis* is much more like *Lithothamnion* in general structure.

[2] Very kindly sent to me by Professor Garwood.

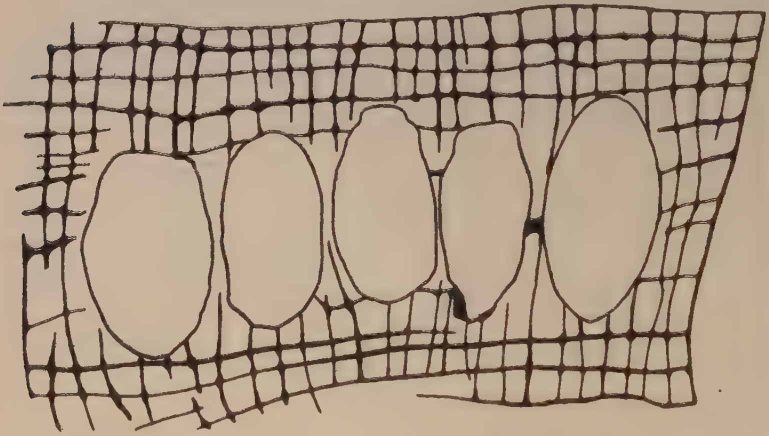

FIG. 11.—*Archaeolithothamnion lugeoni* Pfender, to give an idea of the relation between sporangia and cell-walls (Rao and Pia, 1936, Plate IV. Fig. 2.)

It will have been seen that there is a great doubt about almost all the records of organs of reproduction in the Solenoporaceae, and that no such bodies may safely be said to be present in any form. There are structures in *Solenopora gothlandica* and *S. gracilis*, which are in some ways like the sporangia of *Archaeolithothamnion*, and these bodies, first seen by Rothpletz, may be true sporangia.

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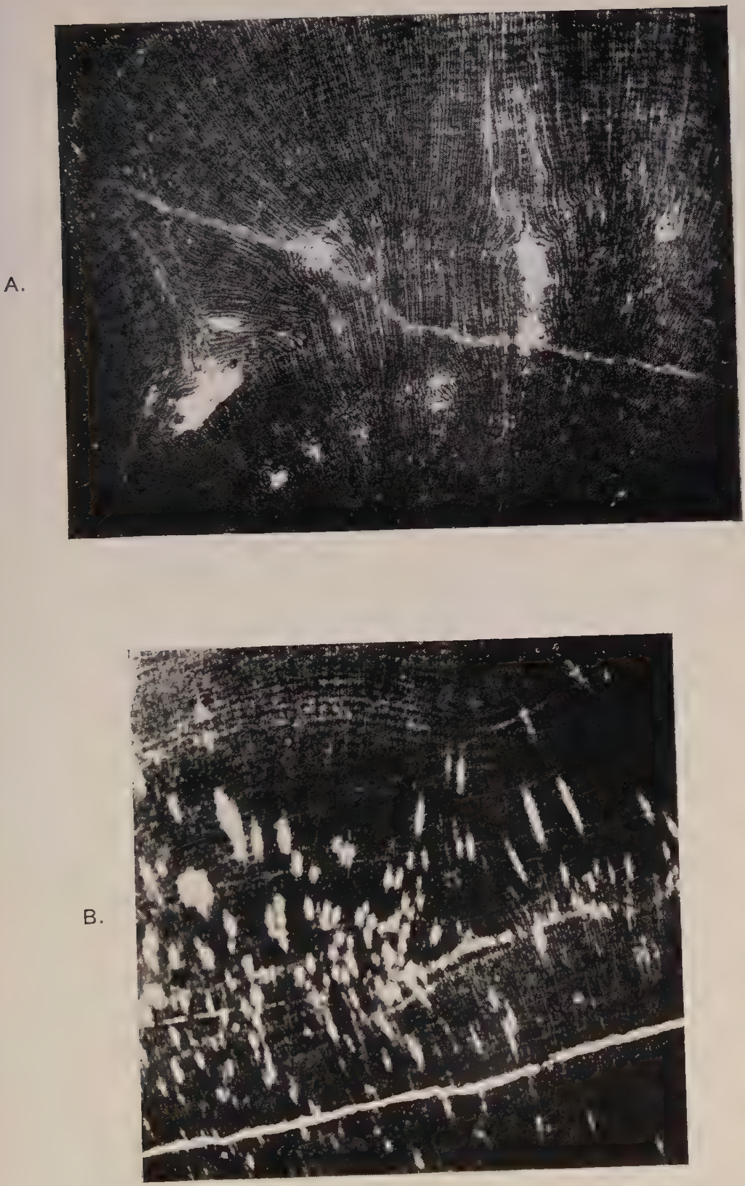
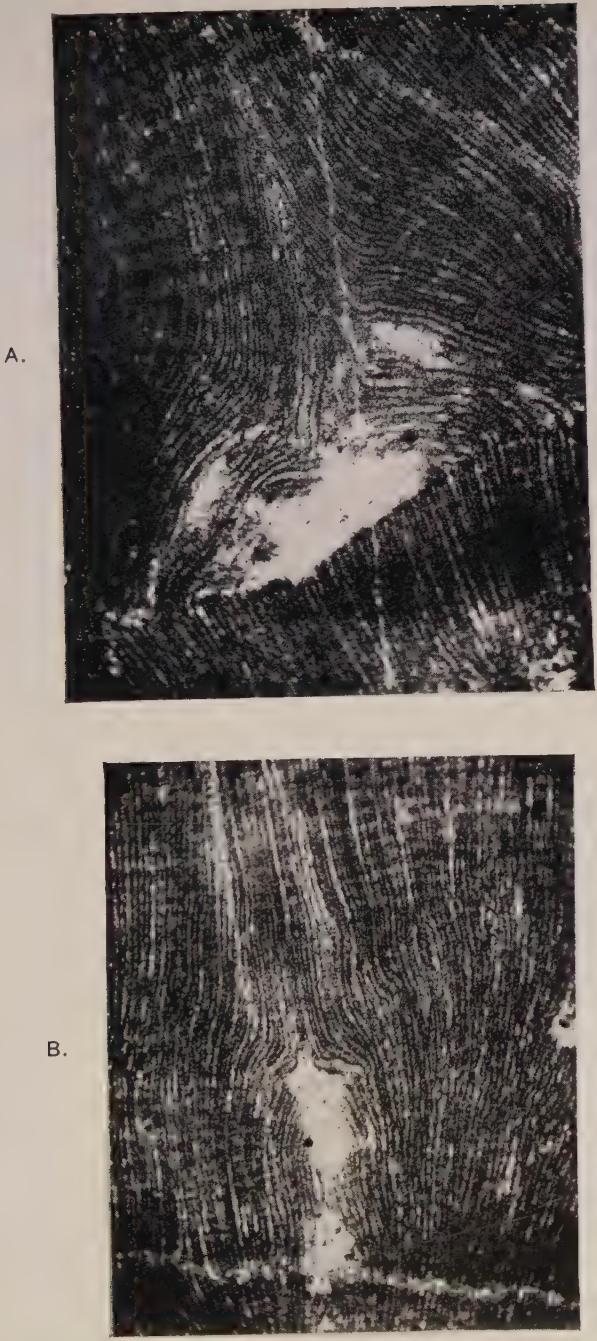


Solenopora gracilis.



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EXPLANATION OF PLATES 5 and 6.

PLATE 5

A.—*Solenopora gracilis* Garwood and Goodyear, Woolhope, Limestone, Old Radnor. X 17. Bodies like the sporangia of Opik and Thomson are seen, having a clear relation with the growth of the alga.

B.—*Solenopora gracilis* Garwood and Goodyear. Woolhope Limestone, Dolyhir Quarries, Old Radnor. x 22.s. Garwood Collection, slide no 394. The 'pseudo-sporangia' of Garwood and Goodyear, which have here quite a different relation to the cell-walls from that seen in Fig. 1.

PLATE 6.

A.—*Solenopora gracilis*. Garwood and Goodyear. One of the structures seen in Plate 5, Fig. 1, X 50.

B.—The same specimen, another of the structures seen in Plate 5, Fig. 1, X 40. Very like the pictures given by Opik and Thomson, 1933.

VISIT TO GEOLOGY DEPARTMENT, IMPERIAL COLLEGE (ROYAL SCHOOL OF MINES), SOUTH KENSINGTON, S.W. 7.

Saturday, 3rd July, 1943.

Report by G. S. SWEETING, D.I.C., F.G.S.

ABOUT 100 members of the Association assembled at 2.15 p.m. in the Geological Dept. of the Imperial College of Science and Technology (Royal School of Mines), South Kensington.

The President (Professor H. H. Read), in extending a hearty welcome to the visitors, referred to the close historical connection between geologists, the Geological Survey and the Royal School of Mines. He remarked that in 1851, when the Royal School of Mines was born, it was linked with the Geological Survey in Jermyn Street, and that the officers of the Survey were the School's first Professors.

Professor Read then briefly outlined the programme of exhibits and proceedings for the afternoon, in which all members of the staff of the Geological Department took part. The following demonstrations were given : Quick-time Weathering, Separation of Micro-fossils from Clays, Oilfield Structures and Oil Migration, Fluorescence of Minerals, Rock-sectioning and Ore Microscopy. The museum, laboratories and library were also open for inspection during the afternoon. Dr. Gilbert Wilson gave a lecturette on "Cleavage in Rocks," in which he briefly outlined the value of rock-cleavage in the interpretation of fold-structures to the field geologist. The talk was illustrated by lantern slides.

At 4.15 p.m. Professor Read very kindly provided an excellent " war-time " tea in the Department, after which a vote of thanks, proposed by Mr. C. E. N. Bromehead, was given to Professor Read and his staff for giving the members a most interesting and enjoyable afternoon.

NEW EXHIBITS IN THE GEOLOGY GALLERIES AT THE BRITISH MUSEUM (NATURAL HISTORY), LONDON.

REPORT OF DEMONSTRATIONS HELD ON 17th JULY, 1943.

By KENNETH P. OAKLEY, Ph.D., F.G.S., and F. E. ZEUNER, D.Sc., F.G.S., F.Z.S.

INTRODUCTION.

ON the afternoon of Saturday, July 17th, about forty members visited the re-opened part of the Geological Galleries at the British Museum (Nat. Hist.). The Keeper of the Department, Mr. W. N. Edwards, explained that owing to the limited facilities available under present conditions it had been possible to open only a small section of the galleries, where a series of temporary exhibits of general interest had been arranged. Some of these might be described as ' experimental ' in character, for it was intended that they should serve as a basis for more permanent exhibits after the war. The new exhibits included : Fossils from the London District (including reconstruction-models of Pleistocene mammals found in the Thames Valley) ; Reconstruction-models of Mesozoic and Tertiary Mammals ; Fossil Vertebrates from Gibraltar (including material obtained during recent tunnelling operations and collected by Major R. V. Dawes, R.A.) ; Fossils and their Environments (illustrating the correlation between invertebrate faunas and rock facies) ; Climatic Battle Fronts (see *P.G.A.*, vol. 54, p. 119) ; Early Geological Maps and the Fossil Collection of William Smith. Two old exhibits, Introduction to Fossils and the Evolutionary Series, had been retained. The Fossil Man cases had been rearranged, and in conjunction with them three new exhibits had been set out : Types of Early Man (busts representing restorations of the Pekin, Java, Neanderthal, Piltdown and Cro-Magnon types); Tools and Weapons of Early Man (a stratigraphical guide series), and an elementary exhibit entitled Man the Tool-maker. The two latter exhibits were demonstrated by the writer, after which Dr. Zeuner gave an account of the restorations of Pleistocene mammals, and Dr. L. R. Cox briefly demonstrated his exhibit, Fossils from the London District. The talks given by the first two demonstrators are summarized below.

K. P. O.

MAN THE TOOL-MAKER

By K. P. OAKLEY.

The employment of tools is undoubtedly a fundamental characteristic of man. All mammals have evolved some specialized bodily equipment in adaptation to one way of life or another ; man alone relies mainly on extra-corporal equipment of his own making which can be quickly changed or discarded as circumstances dictate. It is in *making* tools that man is unique. Apes have been known to *make use* on occasion of natural objects., *e.g.*, as missiles, but the shaping of sticks and stones to particular uses was the first recognisably human activity. Viewed in this way the artifacts of early man have a place in the study of human palaeontology.

The exhibit opened by posing the question, " How old is mankind ? " As with all biological classifications, only an arbitrary line can be drawn between pre-human and human, but if man is defined as the tool-making animal the question can be framed in a way perhaps easier to answer : " How old are the earliest artifacts ? "

Some of the evidence which settled the controversy raging in geological circles in the first half of the last century, as to whether man was a contemporary of the " Antediluvian " animals, was displayed. Evidential specimens shown included one of the implements found by Boucher de Perthes in the "diluvial" gravels of the Somme, and the jaw-bone of Woolly Rhinoceros found with flint-working debris below brickearths at Crayford. There is, of course, no longer any doubt that man existed at the beginning of the "Ice Age." The exhibit went on to deal with the unsettled controversy of this century: "How much further back must we go to find traces of man's earliest handiwork?" The quite skilful, if primitive, craftsmanship of undoubted artifacts dating from the beginning of the Pleistocene suggests that man's first efforts at tool-making are to be looked for in the Pliocene. However, one must expect the earliest artifacts to be practically indistinguishable from the accidents of Nature. Examples of chipped flints claimed by some as representing man's earliest attempts at making tools were exhibited side by side with flints chipped by non-human agencies and apparently indistinguishable from them.

The first tools were made of materials which man found ready to hand: wood, bone, stone. The majority of early implements which have come to light are of stone, simply because this is durable and has survived where wood and even bone have perished. Examples of the use of wood, bone and stone by palaeolithic man were shown.

Human progress has gone step by step with discoveries of better materials for making *cutting* tools. Thus, human history in many parts of the world can be divided into the Stone Age, the Copper Age, the Bronze Age, the Iron Age and now the Age of Steel-alloys. To the human palaeontologist the Stone Age is of the greatest interest, for it took man more than half a million years to pass beyond it, and during that time he was undergoing physical evolution.

Man soon learnt that stones of the hard glassy kinds (flint, chert, obsidian, etc.) are the most suitable for making cutting tools by a process of chipping, but in regions where such readily flaked materials were unobtainable he often substituted any hard rock he could find, although generally showing a preference for finer grained types such as basalt or quartzite. Towards the end of the Stone Age man discovered that he could sharpen the edges of stone tools by grinding instead of chipping. He could then make effective use of rocks like basalt and dolerite and even chose them in preference to flint for making certain classes of tools, such as axes, where toughness was the chief requirement. Grinding gives a truer edge than chipping, and one which can be re-sharpened with minimum of waste. Moreover, the introduction of the polished axe, capable of producing clean cuts in wood, led to greater precision in carpentry and to the use of wood on a larger scale.

Various aspects of the manufacture of stone tools by early man were dealt with in the exhibit: how to distinguish flints worked by man from the accidents of Nature (the 'cone of percussion' is illustrated by reference to a cone of plate glass punched out of the window above by a bomb fragment); the difference between core-tools and flake-tools; the two traditional fashions of making flake-tools (with and without preparation of the parent lump); various techniques of flaking stone; Stone Age nomenclature, and what can be gleaned concerning the culture of Stone Age man by a study of his artifacts. The whole exhibit was designed primarily for the beginner. Lest he be confused by the restricted senses in which such terms as 'culture' and 'industry' are used in literature dealing with stone implements, he is provided with definitions. The sum total of what a particular human society practises, produces and thinks may be called its *culture*. The earliest cultures are known solely by their more permanent products, e.g. stone artifacts. Sets of artifacts which are evidently the work of a single group or of related groups of men constitute *an industry*. Thus, the hand-axe industry in the Swanscombe gravels may be said to represent a Middle Acheulian culture.

A few picturesque examples of what can be deduced from individual types of stone implement were given. From the early appearance of the knife-edged, bifacial type of hand-axe we may deduce that man was not long in developing equipment for dealing with animal flesh, which is noteworthy, for his ancestors of the warm forest regions were probably largely vegetarian. Then, side-scrapers tell of the early use of skins ; hollow-scrapers (used as spokeshaves) of the working of bone and wood. Crude stone sickle blades in a Mesolithic industry attributed to the sixth millenium B.C. in the Middle East, tell of the dawn of the ' Neolithic Revolution,' as the change from food-gathering to food-production made possible by the introduction of agriculture has been styled. Weapons of the Older Stone Age are exclusively weapons of the chase. Organized warfare was unknown until the Stone Age was passing and the effects of the ' Neolithic Revolution ' were becoming manifest in the shape of population-pressure. Thus, the appearance of the first stone battle-axes in Europe, about 2,000 B.C., may be counted a fact in human ecology.

An outstanding feature of the cultural section of the exhibit was the giant flint hand-axe (Middle Acheulian) found in gravels of the Lower Boyn Hill terrace at Furze Platt near Maidenhead, and presented to the Nation by the late Mr. Llewellyn Treacher. Hand-axes, which are among the most characteristic tools of Older Stone Age culture, were not axes in the ordinary sense, but no doubt like jack-knives had many uses. This particular one is clearly the work of a master craftsman, and its exceptional size suggests that it may have had symbolic value to some early palaeolithic hunting group. A minute hand-axe found in the same gravels was exhibited. Such miniature tools are not uncommon in the Middle Acheulian industry. Australian aborigineees make small stone implements as toys for their children, and perhaps palaeolithic man did likewise.

One of the superb ripple-flaked flint knives made in Egypt in Middle Predynastic times was exhibited as probably representing the highest standard of flint working ever attained. Such knives were presumably for ceremonial use.

An important characteristic of evolving man, following from his capacity for tool-making, was his ability to control his environment to an increasing extent. By the kindling of fire, the wearing of clothes and the preparation of dwellings, man was able to extend his environment beyond that of the warm forest lands to which his ancestors were confined. Burnt bones from a palaeolithic hearth were exhibited ; exquisitely finished bone needles used for sewing skins more than 20,000 years ago, and a reconstruction of a pit dwelling of Upper Palaeolithic age excavated in Russia, also served to illustrate this aspect of Man the Tool-maker.

Finally, man is the only animal capable of abstract thinking : that is to say of imagining, of deducing from and of speculating on relationships between things. This abstract thinking has led to science, art and religion, which were at first scarcely separable from one another. In illustration of this aspect of man in the early stages of his evolution, a reproduction of a Magdalenian cave-painting was shown. It is now generally accepted that such works of art were part of a hunting magic. It is possible to see in them, not only the beginnings of graphic art, but perhaps also the beginnings of scientific theory. Dr. Julian Huxley recently recorded the fact that a male gorilla in captivity in this country had been observed tracing the outline of his shadow on the wall of his cage with his forefinger (*Nature*, vol. 149, 1942, p. 637). The earliest cave-art consists of simple outlines, and it seems very probable that man learnt to draw through the idle amusement of tracing round shadows with stone tool in hand. His interest in shadows having been aroused, he would have observed that when an animal moves its shadow moves with it. Having a limited range of knowledge what would be more natural than to deduce that the shadow was part of the animal ? By drawing the *imagined* outline of an animal he would be doing the equivalent of tracing round its shadow. In thus fixing the shadow he gained part of the animal, and this, so he would deduce, surely gave him power over that animal in hunting. Doubtless at the same time he found pleasure in so exercising his imagine-forming faculty. It is easy to see how speculation on the intangible phenomenon of shadows might have given rise to animistic conceptions in the mind of primitive man.

One might sum up by saying that the making and use of tools, art, science and religion arose as integrated parts of man's mental reaction to his environment.

Man's early tools are of interest to the geologist on account of their usefulness as a means of dating Quaternary deposits. The exhibit entitled " The Tools and Weapons of Early Man " aimed at providing for the benefit of students a type series of implements arranged chronologically. The material at present available for exhibition is limited, but it is hoped that a more fully representative series can be displayed after the war. In connection with this exhibit a chart was demonstrated showing the probable relationships between early cultures and the stages of the Ice Age, with an approximate time-scale based on the work of de Geer and Milankovitch.

RECONSTRUCTION-MODELS OF PLEISTOCENE MAMMALS.

By F. E. ZEUNER.

In the part of the exhibit ' Fossils from the London District ' which illustrated the Pleistocene of the Thames Basin, six models of the most conspicuous contemporaries of Palaeolithic Man were included, namely of the Mammoth and the Straight-tusked Elephant, the Woolly Rhinoceros and Merck's Rhinoceros, and the Steppe Bison and the Aurox. The first of each pair was characteristic of the cold environments of the Pleistocene (and therefore mounted on a white foot-plate), the second of the temperate, chiefly forest, environments (green foot-plate). Outline figures of modern man gave an idea of the size of the animals. The scale of the models was half an inch to the foot ; they were the joint work of Miss Ione Gedye, of the London University Institute of Archaeology, and the writer. They will be described in greater detail in the *Proc. Linn. Soc. Lond.*—Part I :—155 (3), pp. 245-251, 1944.

Of the **Mammoth,** excellent reconstructions have been made in recent years, which rely on the numerous Palaeolithic drawings from France and Spain, and on the remains of frozen bodies found in Siberia. The Siberian Mammoth was of about the size of the Recent Indian Elephant, but the European races were mostly larger. With its thick coat of reddish hair and its large, curved tusks it must have looked more formidable than the Recent species. The Mammoth differed from other elephants in its narrow and long skull, the hump over the shoulders and the strongly sloping back.

The **Straight-Tusked Elephant** (*Elephas antiquus* Falc.) was larger than the Mammoth. Much of our knowledge of its body is based on the skeleton found near Upnor, Kent. It had no hump and its back sloped only slightly towards the hind-quarters, so that in appearance it was more akin to the modern elephants, especially if represented with a bare skin. A cave-drawing from Pindal, Northern Spain, however, suggests that it had a kind of mane, and therefore possibly some cover of hair. Its skull is highly characteristic, extremely broad across the alveoli.

The **Woolly Rhinoceros** (*Tichorhinus antiquitatis* (Blum.)) has in the past been figured incorrectly. Fortunately the body found in 1929 in oil-sands at

Starunia (Polish Carpathians) has provided a wealth of important information This, and studies on the skull in relation to neck and body carried out by the writer have been incorporated in the new reconstruction. The Woolly Rhinoceros had no skin-folds ; its body resembled that of the modern White Rhinoceros (*Ceratotherium simus* (Burch.)) of Africa. But it was covered with dense, black hair and had an accumulation of fat over the shoulders, like many other mammals which have to survive a season when food is scarce. The anterior of the two horns was placed on the very tip of the nose ; it slanted forwards and was perhaps used in clearing snow from the pasture in winter.

Merck's Rhinoceros (*Dicerorhinus merckii* Jäg. syn. *megarhinus* de Christol) has not been reconstructed before. The present first attempt relies on the structure of the skull and on the established close relationship with the Sumatran Rhinoceros (*Dicerorhinus sumatrensis* (Cuv.)). The latter is the only Recent species which has a coat of hair, and it has been assumed that the fossil European species also had some kind of a fur. The skin of the Sumatran Rhinoceros is laid in folds, though less so than in the Indian Rhinoceros. This feature, too, has been used in the reconstruction.

The **Steppe Bison** (*Bison priscus* Boj.) probably was nothing but a large, long-horned race of the ordinary Bison (*B. bonasus* (L.)). Since the typical *B. priscus* was a denizen of the loess-steppe, its reconstruction shows a thick coat of hair similar to the winter-coat of the Yak and other central Asiatic ruminants.

The **Aurox** (*Bos primigenius* Boj.), the ancestor of modern cattle, requires little comment. Its reconstruction is based on the drawing discovered by H. Smith in Augsburg and published in 1827. It shows one of the last survivors of this species drawn from life. In order to obtain a more correct picture of the Pleistocene race, a large skull from the Thames Pleistocene has been used in the reconstruction of the head and horns. The fur is shown as almost black, a colour which apparently was frequent—in the bulls (exemplified, for instance, by Spanish Fighting Bulls), while the cows were more reddish-brown. But it is probable that the colour varied a great deal even in the wild species. A slightly curly texture has been given to the fur, taken from modern breeds such as highland cattle, since the latter are adapted to a fairly rigorous climate such as the northern Pleistocene races must have been able to withstand.

THE CRAYFORD BRICKEARTHS

By A. S. KENNARD, A.L.S., F.G.S.

[*Received 28th September*, 1943.]
[*Read 5th May*, 1944.]

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I. INTRODUCTION.

CRAYFORD had its geological centenary six years ago, for it was in 1838 that the deposits were first described when John Morris gave a full account of their extent with a detailed description of four sections and described the contained fossils, including the first record with figures of *Psilunio littoralis* (Cuvier) as a fossil. One may add that it is an excellent account and the figured specimens are in the Geological Survey Museum, London. The abundance of fossils (there was no mechanical digger) soon attracted the collectors and many specimens were secured from the workmen with the usual absence of details of provenance. It was fortunate that there were two resident collectors—Mr. Grantham of Crayford and Dr. F. Spurrell of Belvedere, the father of F. C. J. Spurrell, whose name will always be associated with Crayford. The collections formed by these two men soon became well known and were inspected by, *inter alia*, Professor W. Boyd Dawkins, Dr. Hugh Falconer, Professor J. Morris, Professor J. Prestwich and Dr. S. P. Woodward, and the determinations of the bones were published. It is thus no wonder that Crayford became famous not only in England, but on the Continent. There is no need to give the history of the researches, since it has been done up to 1889 by W. Whitaker [**44***] and this still remains the last word on the subject, but an attempt has been made in the bibliography (p. 161) to bring it up to date. Of great importance was the discovery of the " chipping floor " at Stoneham's pit by F. C. J. Spurrell, who was the first to reconstruct the flint blocks from which the implements were made [**35**], and this work was the inspiration of similar work with Caddington material by Worthington G. Smith.

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* For List of References, see p. 162.

The brickyards are now closed down, for " Thames reds " have given place to " Flettons," and though some sections still remain it is unlikely that much fresh evidence will be obtained. Crayford figures so largely in Pleistocene geology that no apology is needed for an attempt to collect all the available evidence and to see what legitimate deductions can be drawn from it.

The Crayford Brickearths cover a large area, for fluviatile deposits and numerous excavations have been made between Stoneham's Pit and the river at Erith. The various pits have received names, usually from the owners, but owners change and the earlier names are soon forgotten. Visitors, too, have muddled the names so that now it is often impossible to identify the pits referred to by older writers. Morris described four sections, giving the locality as Erith, probably because that name was better known [**1**]. Of these, one is certainly " Stoneham's " at Crayford, whilst " Francis and White's " is the Erith pit, which in 1867 was called " White's " by Boyd Dawkins [**12**]. The two other pits noted by Morris as " Hutchinson's " and " Mr. Clarke's " cannot be traced, though they were probably at Slades Green. It is interesting to note that Lydekker, in his catalogue, notes purchases of bones from Slades Green (miscalled Slade Green) as early as 1846, and from Erith in 1849, yet the earliest date for Crayford is 1862 [**40**]. In 1867 Boyd Dawkins mentions " Stoneham's " and states that the whole of the Grantham and Spurrell collections came from it [**12**]. This is not probable, though the bulk certainly did. In 1872 the Rev. O. Fisher, when describing the first flint flake from the deposits, called the pit from which it came " Slades Green," though it is obvious from the description that it was " Stoneham's," and this has caused trouble. In 1886 F. C. J. Spurrell noted " Stoneham's " (which he called " North End Crayford "), Slades Green, Rutter's and Furner's pits [**42**]. Norris' pit, which Whitaker in 1889 described as a new pit [**44**], was in 1892 often called the " North End " pit. Hence it is impossible to ascertain exactly the pit meant, even when one is named, though there can be no doubt that the majority of specimens came from Stoneham's. Since, however, it is clear that the sequence is the same in all the pits this is of no importance.

My own personal collecting at Crayford was between 1892 and 1900, and then the re-opening of the brickearth pit at Grays, the opening of the sections in London Wall and Dierden's Pit, Swanscomb, as well as of those in the new reservoirs at Tottenham, claimed all my spare time. At Crayford my collecting was confined practically to Rutter's new pit and Stoneham's, for these were by far the richest in fossils, but I am afraid my inexperience missed some points in stratigraphy which would have helped in the solution of the various problems now presented to us. Rutter's new pit was on both sides of the Erith-Crayford road, the two workings being connected by a tunnel, and since the sections differ greatly they are called Rutter's pit E. or W., as the case may be. The former has also been called the recreation or football-field section in later years.

Like that from other Pleistocene deposits the material from Crayford is somewhat scattered. The greater part of the vertebrate remains are in the British Museum (Nat. Hist.) and the Geological Survey Museum, for this part of the " Spurrell " Collection was divided between these two national institutions. The collection should be called the " Spurrell's " Collection, for it was the work of two generations ; W. Boyd Dawkins' Collection is in the Manchester Museum, while many of the smaller vertebrate fossils are in private

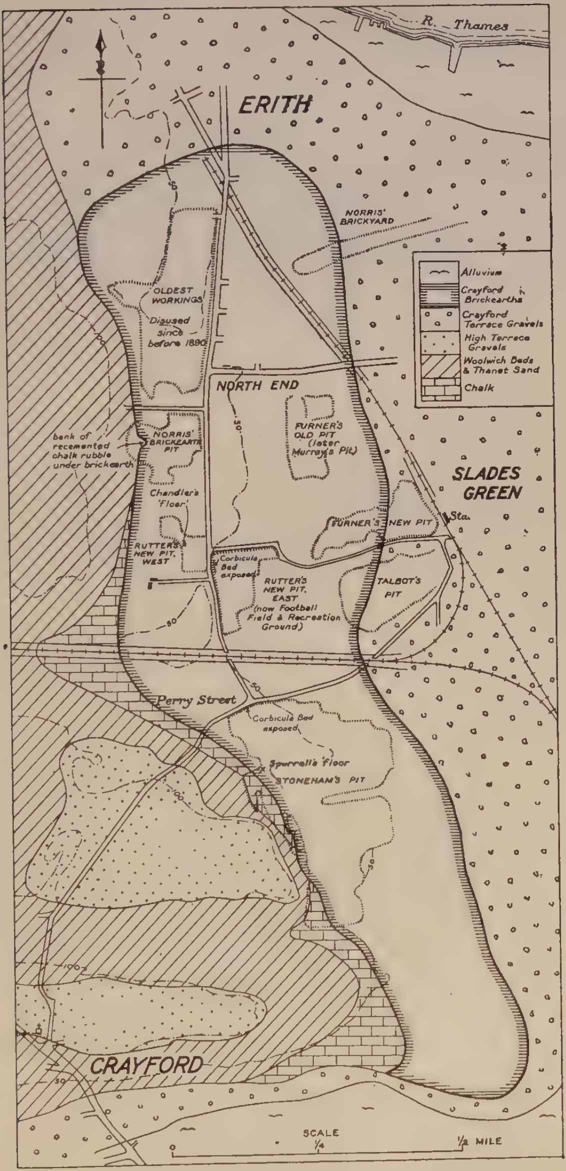

FIG. 12.—Map of the Crayford Deposits.

hands. I have been unable to obtain any information as to the Grantham Collection. As to the mollusca, large series are in both the Geological and British Museums, principally from the " Spurrell " Collection, but the Geological Museum has in addition the collection of that keen collector, the late W. J. Lewis Abbott. I still retain my own collection, since I hope to do more work on it. The British Museum (Nat. Hist.) has the unique series of human artefacts collected by F. C. J. Spurrell.

My thanks are due to many kind friends who have placed their knowledge at my disposal, and especially Mr. R. H. Chandler, Mr. C. P. Chatwin, M.Sc., Dr. F. Haas, Mr. M. A. C. Hinton, F.R.S., Dr. A. T. Hopwood, Dr. J. W. Jackson, F.S.A., Mr. Day Kimball, F.G.S., Mr. A. L. Leach, F.G.S., Dr. K. P. Oakley, F.G.S., Prof. H. H. Read, F.R.S., and Mr. Gilbert White. Tribute must also be paid to those friends who have passed the bourne, notably Dr. O. Boettger, Dr. F. Corner, Dr. A. C. Johansen, J. P. Johnson, E. T. Newton, W. Whitaker and B. B. Woodward, who so materially helped me in my younger days. The author also wishes to acknowledge the use of the photographs on Pl. 7.

II. NOTES ON THE DEPOSITS AND THEIR FOSSIL CONTENTS.

(a.) General.

Such full accounts of the deposits have been given by Morris [**1**], Dawkins [**12**], Tylor [**19**], Whitaker [**44**], Chandler and Leach [**69, 77, 79**] that there is no need to repeat all their statements. Owing to the lenticular character of fluviatile sands and gravels there is but little constancy in the details of succession. Whitaker states that Dawkins in 1867 [**14**] could not find the divisions noted in 1838 by Morris [**1**] and that he himself could not collate his divisions with those of Dawkins [**44,** p. 467]. Apart from a few minor errors of no importance, there is no reason to doubt the accuracy of the published sections except the generalized ones. The early workers did see what they say they did, but what was there one year was replaced in a short time by a different facies, though the main divisions can usually be recognized. The Pleistocene beds at Crayford lie on a well-marked bench cut in the Chalk at about zero O.D. This is the Bench D of Day Kimball [**113,** p. 26] and all the beds must be later than the cutting of this bench. As to their area, Morris states : " The deposit at Erith is situated to the south of the town extending nearly to Crayford and averaging about 300 yards wide. It reposes on the Chalk, though sometimes separated from it by a bed of sand containing rolled specimens of the plastic clay shells " [**1**]. The additional facts to add to the first account are that the basal bed is often gravel and " on the west the drift is banked against and bounded by a buried cliff of Chalk and Lower Tertiaries on the east the drift passes beneath the recent Alluvium of the Thames and Darent " [**69,** p. 137]. Morris' estimate of the width was only for the brickearths and not for the Crayford gravel, which has a much greater extension. R. H. Chandler informs me that in his opinion the width of the brickearths is about 700 yards, and there is certainly no better authority.

It is now generally admitted that there are three well-marked divisions in the Crayford series.

1. The basal sands and gravel, the 'Crayford Gravel' up to 15 feet.
2. The Lower Brickearth including the *Corbicula* Bed ; the former attaining to 30 feet in thickness and the latter 5 feet.
3. The Upper Brickearth, including the 'trail' up to 20 feet.

(b.) The Crayford Gravel.

All the writers from Morris have recorded this bed, though Tylor was the first to recognize its importance [**19**]. He states that at Erith " on top of the

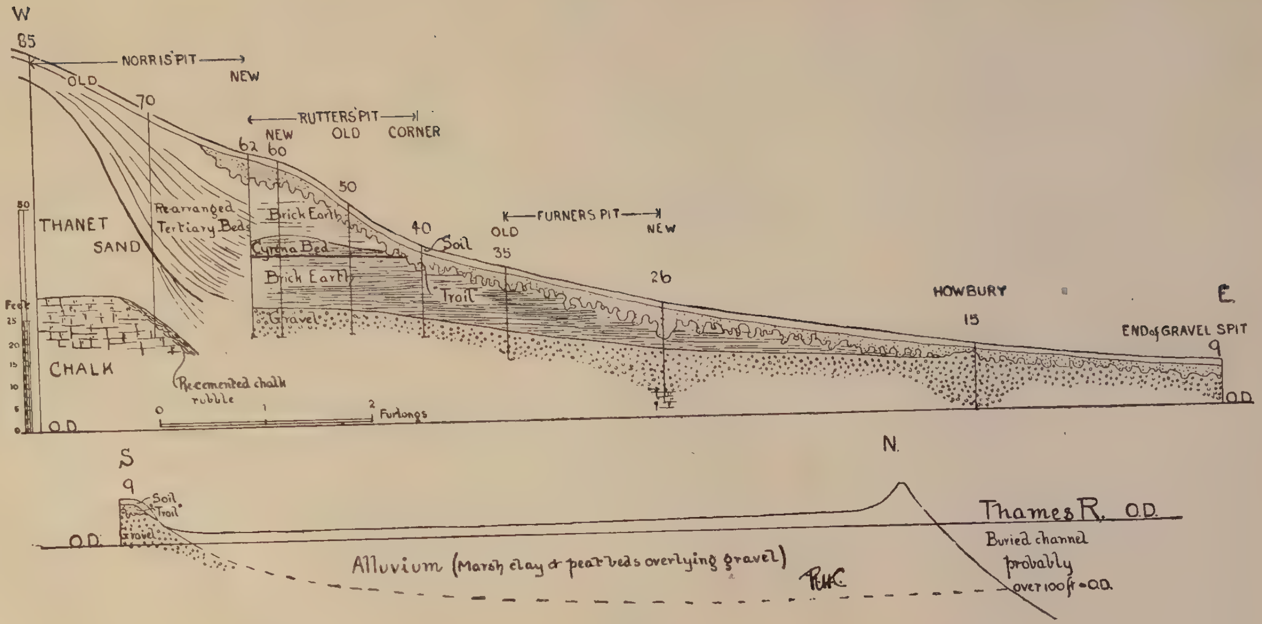

FIG. 13.

Scale diagram constructed from actual sections in the Crayford Brickearth and Gravel pits (1913) R. H. Chandler. (*Proc. Geol. Assoc.*, vol. xxv, 1914, p. 63.)

Thanet Sand lies a bed of sand and gravel which fills up all the hollows of the underlying Thanet Sands and Chalk and smooths over all previous inequalities" [**19**, p. 90] and at Crayford he notes there was six feet of coarse gravel [**19**, p. 91]. F. C. J. Spurrell states that this gravel yields flint implements of an earlier type than those from the working floor [**42**, p. 25] and one implement is in the British Museum (Nat. Hist.). Vertebrate remains also occur, and being labelled "Crayford" or "Slades Green" have caused confusion. It is almost certain that all the teeth of *Elephas antiquus* Falc. came from this gravel and not from the overlying brickearth. Whitaker states: "Contrary to what one would expect the beds rise slightly eastward, that is towards the marshes and as the ground falls slightly in that direction the upper beds end off" [**44**, p. 439], so that at Slades Green the basal gravel is alone present and this at Howbury is ten to fifteen feet thick. This rising towards the east would lead one to infer that the eastern bank of the river was not far away, but this has long been destroyed. The surface of this gravel was certainly a land surface before the lower brickearth was deposited, for R. H. Chandler has noted that flint artefacts were abundant on top of the gravel at the base of the brickearth [**84**].

The Crayford Gravel is probably much earlier than the succeeding brickearth and may well be connected with the cutting of the bench. One can safely say that this gravel represents a torrential stream and one of considerable size. It has been suggested that when the uplift at the close of the High Terrace stage occurred, the Darent was unable to breach the Chalk anticline at Dartford and was diverted west to join the Cray near Crayford, the present course of the Darent having been cut later [**42**, p. 23]. I have failed to find any evidence in support of this view and feel confident from a section at East Hill, Dartford, that the Darent did cut its present course during the uplift. There is a tendency to assume that these uplifts were slow and continuous, but the field evidence is against this view and supports the claim of a rapid uplift. Both at Swanscomb and at Crayford the basal gravel is clearly that of a torrent and not of a slow moving stream. At Swanscomb the basal gravel is composed mainly of material derived from pre-existing beds mainly deposited by a slow stream. These were all swept away by the rush of the river, and slow stream conditions did not return until much later. I have used the term 'uplift' for convenience and it is of no importance in the present context whether the land rose or the sea went down. The facts are that there were these differences in the relative levels of sea and land and the cause of these differences is another story—of theory based on theory.

(c.) Lower Brickearth, including Corbicula Bed.

The Lower Brickearth, including the *Corbicula* bed, has yielded nearly all the organic remains for which Crayford is famous. The brickearth proper often contains lenticular patches of sand and pebbles denoting transient currents, but the brickearth itself is clearly the product of slowly moving water, and is not flood loam. Molluscan evidence (p. 159) shows there was but little aquatic vegetation. Mammalian remains occur scattered throughout, usually as single bones, though a few conjoined bones have occurred, but nothing approaching a complete skeleton. Mollusca often occur as noted by Whitaker [**44**, p. 439], but they are not common, the richest section being Rutter's new pit (W.).

The larger bivalves, *Anodonta*, *Corbicula* and *Psilunio*, are often in the position of life and one can infer that the deposition of the brickearth was fairly quick and that in the place where the shells occur in that state there was no current to disturb the bed. Bivalves are often said to be in the "position of life" when the valves are united, but a stroll on the foreshore at Wandsworth would soon dispel this error, for one can collect hundreds of dead shells with the valves still united by the ligament. In Rutter's new pit (W.), where the brickearth was rather sandy, one could detect the presence of *Psilunio* and *Anodonta* by the discoloration of the surrounding matrix, presumably arising from the decay of the contained animals. Crayford is the only Pleistocene deposit I have seen where one could say positively that the shells lived where found.

It is curious, as noted by Morris, that vegetable remains are practically absent from the brickearths, for the abundance of large herbivorous mammals shows that there must have been an extensive vegetation to provide them with food. The only record is of the Sweet Chestnut (*Castanea sativa* Mill), " found in the lowest part of the brickearth together with Palaeolithic flakes " during an excursion of the Geologists' Association by H. N. Ridley [**41**]. The overlying *Corbicula* Bed is very variable in thickness. In Stoneham's Pit it is a lenticular patch not reaching the buried cliff and dying out towards the alluvial marsh. In Rutter's new pit (W.) it was said to be " one foot to south and at the north end six to eight feet of clean false bedded sands many shells of *Unio* (*Psilunio*) and *Anodonta* in the position of life " [**77**, p. 188], but in my opinion this was a sandy phase of the Lower Brickearth. In Rutter's new pit (E.) it was a well-marked feature about six feet from the surface, and a foot in thickness ; shells and small bones were common in patches. Rolled fragments of brickearth were very common in the sand, showing that there had been erosion of the underlying brickearth. At Erith the *Corbicula* Bed was four feet at the most (Whitaker, **41**, p. 434). This bed has yielded nearly all the small vertebrates, for when dry it could be easily sieved and the residue taken away for examination.

The *Corbicula* Bed shows that there was again a flowing stream and that the barrier which had produced the Lower Brickearth was not functioning. It is difficult to estimate the combined thickness of the Lower Brickearth and the *Corbicula* Bed, but 35 feet is probably the maximum. The suggestion that " the lemmings and other rodents have burrowed into the sand at a later time " [**113**, p. 44] can only have been made by one who had no personal knowledge of the bed. The bones and teeth are usually fragmentary and the jaws rolled and broken so they have clearly been drifted to where they are found. The view that the *Corbicula* Bed is distinct from the Lower Brickearth and represents different climatic conditions [**114**, p. 44] is at variance with the facts. In 1895 I published a list of the results obtained by washing 20 lbs. of brickearth from Rutter's new pit (W.), obtained from the middle of the lower bed. This yielded 206 shells and 2 vole teeth [**52**], but much better results as regards microtine remains and shells could be obtained from the *Corbicula* Bed, so except for the large specimens the brickearth was neglected as a source of this material.

The species of mollusca found in the Lower Brickearth itself were :—

Freshwater species.

Bithynia tentaculata (Linné)	23
Valvata piscinalis (Müll)	23
Lymnaea peregra (Müll)	3
,, *palustris* (Müll)	4
,, *truncatula* (Müll)	8
Planorbis corneus (Linné)	6
,, *planorbis* (Linné)	7
,, *leucostoma* Millet	2
Sphaerium corneum (Linné)	69
,, *dickinii* Clessin	4
Corbicula fluminalis (Müll)	3
Pisidium amnicum (Müll)	46
,, *subtruncatum* Malm	6

Land species.

Pupilla muscorum (Linné)	1
Cepaea nemoralis (Linné)	2 fragments

This list reflects the conditions under which the brickearth was deposited, namely slow-moving water ; the numbers of individuals differ markedly from those given under each species in my list, which is from the *Corbicula* Bed, with its preponderance of stream species. In addition to the species cited the Lower Brickearth has yielded all the examples of the three species of *Anodonta*, of *Psilunio littoralis* (Cuvier) except for two or three young and all the largest specimens of *Corbicula fluminalis* (Müll), as well as the only perfect examples of *Cepaea nemoralis* (Linné). Their rarity or absence in the *Corbicula* bed arises from the sorting action of a quick-flowing stream. They did live during the deposition of that bed, but have left few traces behind. The Anodontas and Psilunios only occurred to me in Rutter's new pit (W.), which was opened after F. C. J. Spurrell had left the neighbourhood, but there are a number in the Spurrell Collection which must have come from Stoneham's. These shells never live far from the river bank, though their dead shells are carried to the shores and midstream. In the Thames of today they live up to six feet from the shore, and in North America the limit is twenty-five feet. This will account for their presence in Rutter's new pit (W.), which was very close to the buried cliff and their absence in the East pit, which was much farther away.

The more one studies these enormous brickearth and gravel spreads, the more one is impressed that great volumes of water were necessary to account for their carriage and deposition, and that the present streams would be quite inadequate for the task even allowing for the diminution due to man. Their catchment area is not likely to have been much larger, so that one can only conclude that the rainfall was much greater and that "the Pluvial period" of A. Tylor [**19**] is not a myth, but merits more attention than it has received of late years. There can be no doubt that the Lower Brickearths and the *Corbicula* Bed belong to the same period and denote the same climatic conditions.

(d.) Upper Brickearth.

The Upper Brickearth has yielded few fossils, but has been the subject of much speculation. Tylor was the first to suggest that it had a different origin from the lower beds. He states : "The material for the beds *e* and *d* seems to have descended from A (86 ft. O.D.) and to have been brought by land floods and contains bones, but no shells except the derived ones (i.e. Eocene). On the contrary *b* (*Corbicula* Bed) is full of shells deposited quietly. Many of the species are extremely delicate and are found quite as perfect as recent specimens ; the two series of deposits are interstratified together at D, the eastern bed (*b*) being of fluviatile origin and the western (*d*) being apparently of pluvial origin and more due to land floods ' [**19**, p. 86]. Since the Upper Brickearth yields only a few fossils, little attention was paid to it, but A. L. Leach notes that "the upper brickearths are seen to be thinly bedded and much more clayey than the lower beds" [**69**, p 137]. Hence one could infer that the materials of the two deposits had been derived from different areas. The mammalia known to occur in the upper beds are *Elephas primigenius*, *Rhinoceros antiquitatis* and *Equus caballus*, species that are common in the Lower Brickearth and also have a very long range in time.

Many years ago A. L. Leach sent me some molluscan remains he had obtained from the Upper Brickearth. They occurred as a small patch and were badly preserved and one could only determine them as "*Pisidium*, sp., small species." These indicate the presence of a small pool with vegetation. Thus, there was at least one pause in the accumulation long enough to enable the shells to colonize the pool. In countries of low relief *Pisidia* do not occur under "periglacial conditions." From the sections seen in Stoneham's pit where the buried cliff was well exposed, it was clear that Tylor was right in considering the Upper Brickearth to be the result of sludging from higher ground during a period of heavy rainfall. In Stoneham's pit one could trace the lines of pebbles following the contour of the cliff and descending lower and lower as they were traced in an easterly direction. Sludge deposits occur in other valleys south of the Thames. The brickearth at East Wickham, which has yielded a fairly large Pleistocene faunule including *Ovibos* and *Microtus nivalis* (Mart.), is also sludge. Judged by the microtines it has a similarity to the Lower Crayford Brickearth.

In the Ebbsfleet Valley at Northfleet occurs the sludged mass of chalk rubble that covered the chipping floor, and this has yielded the same three mammals as the Upper Crayford Brickearth. This rubble has been miscalled "Coombe rock" and attributed to "glacial" conditions, but this conclusion is based on theory and not on facts. If the animals were contemporary with the deposition of the bed there must have been abundant vegetation and this scarcely suggests "glacial" conditions, though it is not incompatible with a colder climate. In the Medway Valley there are a number of chalky sludges similar to the Ebbsfleet "coombe rock" ranging in height from 350 ft. O.D. to about O.D. In Batchelor's Pit, Halling, is a fine section cut through the deposit. This shows a chalk cliff buried by a mass of sludge. As this is followed downhill, so the material becomes finer and finer and in places is well bedded. This latter facies has yielded a characteristic molluscan faunule as well as two tusks of *Elephas* sp. The shells are delicate, but well preserved and there is no reason to doubt they were contemporary. So far from indicating cold conditions they point the other way, for one abundant species, *Abida secale* (Drap.), is quite a southern form. It may well be that there was more than one period of "sludging" in Pleistocene times, but this can only be proved from the contained fossils and from these it is certain that in the Medway Valley there was only one, no matter at what height the sludge deposits occur.

It has recently been stated that the Upper Brickearth "is probably a weathered and decalcified loess" [**113**, p. 44]. Since it contains bones and shells it is scarcely decalcified. It is unfortunate that the word "loess" has been used for it has two implifications. Originally it was the equivalent of our brickearth and considered to be a flood loam ; Prestwich always uses it in that sense. Then came the "Steppe and Tundra" theory, and the loess, in order to support the theory, must be considered as of aeolian origin and this is the modern usage of the term. The palaeontological evidence supports the older view. One characteristic of the loess is the abundance of slug remains and the shells of the damp-loving genus *Succinea* ; these do not flourish in an arid region, though they would in an area subject to inundation. Having examined a large amount of Continental material it may safely be said that the "loess" of Continental writers includes a number of deposits of various ages and denoting varying conditions, but not one indicates steppe conditions, or is of aeolian origin. As to the theory, it is better forgotten, based as it is on very imperfect data, misidentifications and wishful thinking [**45a**]. Nehring cites 21 species of mammalia as characteristic of the steppes [**45a**, pp. 47-9]. Of these, only one occurs at Crayford (*Equus coballus*) and that is a complex, whilst another, the Saiga antelope, though it does occur in England, is extremely rare. Nehring also cites 56 other species as occurring and of these, 30 either still live or lived in historic times in England. The latest view of the Mississippi loess is that it indicates wetter and warmer conditions than now exist [**110a**]. It is unfortunate that the Upper Brickearth has yielded so few fossils, but if the Medway deposits are its equivalent a very long period of time elapsed between the *Corbicula* Bed and the deposition of the Upper Brickearth, with a marked change in climate. From the mollusca the Medway deposits appear to indicate a climate similar to that of today, whilst the lower brickearth at Crayford was certainly much warmer.

(e.) Brickearth in Railway Cutting (Dartford Loop).

This section, which may represent the east bank of the river, was first noticed by Dawkins in 1867 [**14**], described by Whitaker [**44,** pp. 440 and 447] and figured and described by Prestwich [**51,** pp. 152-3], though it must be admitted that the two latter are not in agreement. It would appear that Prestwich gave a generalized section, hence the differences.

It is, however, clear that the section was very similar to that at Stoneham's pit with a buried chalk cliff and beds of fossiliferous drift banked against it. So far as they go the contained faunule of Mollusca and *Elephas primigenius* Blum (Geological Museum) supports the view that these beds are of the same age as the Crayford Lower Brickearth.

(f.) Sequence of Events.

1. Cutting of the bench at base level circa O.D. and deposition of the Crayford gravel by a quick-flowing stream.

2. The surface of the gravel becomes a land-surface, probably due to a lowering of the base-level, about O.D. to — 20 ft. O.D., forming a bench missing at Crayford, but well-marked both above and below this locality.

3. Deposition of the Lower Brickearth by a slow-moving stream, and aggradation to about 30 ft. O.D. The aggradation was certainly due to a barrier and since there is no evidence to support the view of a local one, most likely a rise in the base-level was responsible.

4. Deposition of the *Corbicula* Bed, showing that the stream was flowing strongly at about 35 ft. O.D., and that the barrier was no longer functioning.

5. Formation of the Upper Brickearth and Trail, the result of sludging from the higher ground during a period of greatly increased rainfall. There may well have been a land surface on top of the *Corbicula* Bed, but this would have been destroyed by the sludging and is not recorded.

The Upper Brickearth is obviously later than the *Corbicula* Bed, but the evidence is so scanty that it is impossible to estimate the interval between them ; it is probably considerable.

III. VERTEBRATE FAUNA.

(a.) General.

Modern palaeontological work on vertebrates is on a very different level from that of the early work when trivial determinations were too often made on size alone and when there was but little recent material available for comparison. Many of the early determinations would be given only a generic name today and in the *Bovinae* not even that. A fair proportion of the Crayford forms are extinct and of these no complete skeletons are known. Even with recent species there is still much to be learnt of the range of variation due to age, distribution and sex. We are fortunate that, thanks to M. A. C. Hinton's work, our knowledge of the microtine species is now in a satisfactory state, and these form a fair proportion of the Crayford faunule [**94**]. Their exact provenance is also known, for they practically all come from the *Corbicula* Bed. A. T. Hopwood has also given an excellent account of many Crayford specimens with full measurements, tabulating them with similar examples from other Pleistocene deposits [**110**], so that our knowledge, though still imperfect, has been placed on a better basis. As to the larger mammals, nearly all the bones that have survived came from the Lower Brickearth, but a few are from the

Upper Brickearth as well as the gravel. The specimens are at present not available, but their provenance should be determinable from their condition.

One often sees reference to "cold fauna" or "cold loving fauna," usually consisting of three or four species. Such "faunas" do not exist; for all mammals are warm-blooded and therefore prefer warmth. Temperature plays but a small part in their distribution. Food and enemies are of far more importance, and of their enemies internal parasites such as Cestodes and Trematodes play a greater part than is often assigned to them. These parasites, with their cycles of existence, may account for some of the anomalies of distribution. The absence or presence of the intermediate host may enable a mammal to swarm in one area and to be rare or absent in another. The lives of all mammals are extremely complicated and most have to live where they can and not where they would prefer. Nearly all mammals are very adaptable, for they respond quickly to environment. Thus, the tiger in Amurland has a magnificent thick pelt, whilst in India its pelt is thin. There is a similar difference in the Kashmir goat of the mountains, and of the valleys. The "Real cashmere" of commerce is only obtained from the former. No deductions can be drawn from the present distribution, for man has for ages been changing that by his activities and in England has extirpated six of the larger indigenous species, and but for preservation the total would be eight. It is curious how abundant are bones of mammals in Pleistocene deposits and how rare in Holocene, except at human occupation sites. This applies not only to the larger species, but also to the microtines, so that it would appear that the mammalia were far more abundant in the Pleistocene than in the Holocene, with the natural inference that ecological conditions were better in the former.

The various described and figured specimens from Crayford are given in the sequel with their present provenance when known and the date and author of the first record. It is possible that two or three were incorrectly recorded, but this cannot be proved.

Dr. A. T. Hopwood [**110**, p. 15] has published a statistical summary of the Crayford-Erith faunule based on the specimens in the Geological Department of the British Museum (Nat. Hist.) and the Geological Survey Museum, as follows :

Proboscidea	29.3%
Rhinoceros	18
Equus	18.4
Bovinae	16.1
Cervidae	10.2
Felidae	4
Bear	1.4
Canidae	2.6

One cannot help thinking that owing to selective collecting these figures may be incorrect. Those for Carnivora are probably too high, and for the Elephants and Rhinoceros too low. When I was visiting the Crayford pits the men never troubled about the larger bones, for no collector wanted them. They saved all the teeth and the medium-sized bones, but certainly did not trouble about the smallest ones, except "Rat's heads," as they termed *Citillus*.

(b.) Mammalia from the Crayford Brickearths.

Homo sapiens Linné. Only known by his flint artefacts, which are fairly common (see p. 139). First record, O. Fisher, 1872 [**23**].

Canis cf. *lupus* Linné. Very rare. Specimens in British Museum (Nat. Hist.) and Geological Museum. First record, W. B. Dawkins, 1867 [**12**]. Dr. A. T. Hopwood states : "The Specimens are relatively small and may represent a stage in the evolution of the recent species from *Canis etruscus* Major" [**110**, p. 15].

Vulpes cf. *vulpes* (Linné). Very rare. Examples in British Museum (Nat. Hist.) and Geological Museum. Two species of the Canidae are certainly present, a large and a small one, but the specific determinations are doubtful. They are always very rare in fluvatile beds and their burrowing habits make the abundant cave specimens too often suspect.

Ursus arctos Linné. Very rare. Specimens in British Museum (Nat. Hist.) and Geological Museum. S. H. Reynolds has figured and described "Part of cranium from Crayford" (B.M. No. M5041). Only the teeth of the right side and the neighbouring portion of the palate are figured. This is "labelled *U. spelaeus*, but as all the upper premolars are represented it seems better to attribute it to *U. arctos*" [**70**, Pl. V., f. 1]. So far as the evidence shows, *arctos* Linné is the only bear present at Crayford, but there is a humerus in the Manchester Museum determined by W. Boyd Dawkins as *Ursus horribilis* that needs examination. Though an adaptable species, *arctos* has apparently a preference for woodland. First record, W. Boyd Dawkins, 1867 [**12**].

Felis spelaea Goldfuss. Rare. Figured specimens by W. Boyd Dawkins [**10**], *Os innominatum* [**10**, Pl. III., f. 1], British Museum (Nat. Hist.) 23733.

Left ramus [**10**, Pl. I., f. 3], Brit. Mus. (Nat. Hist.) M5029.

Metacarpal [**10**, Pl. XIX., f. 6], Brit. Mus. (Nat. Hist.) M5035.

Metatarsal [**10**, Pl. XIX., f. 7], Brit. Mus. (Nat. Hist.) M5037.

Specimens noted by W. Boyd Dawkins [**10**, p. 152]. Two fragments of the right ramus containing the canine and 3rd and 4th premolars, British Museum (Nat. Hist.) 40967. The distal extremity of the right humerus, British Museum (Nat. Hist.) M5039. A gigantic canine, not traced, but there is a cast in the Geological Museum (Morris Coll.). Some of the bones indicate very large individuals, a fact which does not support the theoretical view of "cold conditions." First record, J. Morris, 1838 [**1**].

Hyaena spelaea Goldfuss. Known to me only by a coprolite in the Geological Museum (Spurrell Coll.) and one in the Manchester Museum (Boyd Dawkins Coll.). This species occurs in all the published lists of Crayford mammals and the verified specimens are certainly not the basis of the original record. First record, J. Morris, 1838 [**1**].

Equus caballus Linné. Common. A. T. Hopwood has published a number of measurements of limb bones of Crayford horses from specimens in the British Museum (Nat. Hist.) : two radii, two tibiae, four metacarpals III, six metatarsals, III, and three proximal phalanges [**110**, pp. 17-20]. He considers that only one species is represented. The horse has a preference for open grassland, but it flourishes in the New Forest, which is a mixture of woodland. First record, J. Morris, 1838 [**1**].

Bison priscus Bojanus. Not common. Calvarium from Erith, in British Museum (Nat. Hist.) 45849. First record, W. Boyd Dawkins, 1872 [**22**].

Bos primigenius Bojanus. Common. There is a ramus in the British Museum (Nat. Hist.), 36240, presented in 1862 by C. M. Doughty, better known for his explorations in Arabia. First record, J. Morris, 1838 [**1**].

A. T. Hopwood states : "If, however, the horn-cores indicate that both genera (Bos and Bison) are represented' it is extremely difficult to identify correctly the associated bones," and his published tables of measurements of metatarsals from Brundon and Ilford emphasize this [**110**, pp. 24-26]. At Crayford, horn-cores of both species occur. It would appear that in England, Bison is the older form, for it is the only Bovine in the High Terrace of Swanscomb, and it is also the only bovine in the High Terrace of France. Both species would appear to indicate woodland conditions.

Cervus elaphus Linné. Common. Numerous specimens in the British Museum (Nat. Hist.) and Geological Museum and a series in the Manchester Museum. A. T. Hopwood has figured " Base of antler ; brow-torse in ' high position ' from Slades Green " : British Museum (Nat. Hist.) 23728e [**110,** p. 22, f. 18]. Falconer, who examined the Grantham and Spurrell Colls. in September, 1863, states that some of the antlers were very large, " nearly to fit *Strongyloceros spelaeus*," and that in the Spurrell Coll. there was " a very doubtful fragment of Reindeer antler (probably *C. elaphus*), but no other indication of Reindeer or of any other species of *Cervus* " [**15,** vol. ii, p. 478]. There is in the Geological Museum (Spurrell Coll.) a small antler lacking the bez tine, an aberration known to occur in *C. elaphus* Linné. The presence of these large examples would lead one to infer woodland conditions. First record, J. Morris, 1838 [**1**].

Cervus eurycerus Falconer. This is the Giant Deer of the Pleistocene and is quite distinct from *Cervus megaceros* Hart, the so-called Irish Elk. There is a magnificent frontal and antlers of *C. eurycerus* from Walton-on-the-Naze in the Geological Museum. The trivial name *eurycerus* may be challenged on the ground that the original *eurycerus* Falc. was a mixture, yet there can be no doubt that Falconer knew that the two forms were distinct. It may be noted that the index to the Memoirs is very incomplete and that all the references to *eurycerus* are not included.

Very rare. Only known with certainty by a mandibular ramus in British Museum (Nat. Hist.) M5078, Spurrell Coll. There is, however, a fragment of antler and a fragmentary mandible with teeth in the Manchester Museum identified by W. B. Dawkins as this species, and they should be re-examined. First record, J. Morris, 1838 [**1**].

Elephas antiquus Falconer. Very rare. Figured specimens.

The second right lower true molar in very early stage of wear, Slades Green, British Museum (Nat. Hist.) 4099, purchased 1846. Figured by Falconer and Cautley [**4,** Pl. XIVA, Figs. 10, 10a] and noticed by Leith Adams as being possibly the opposing molar to the next [**31,** p. 28] ; see also Falconer [**15,** vol. ii, p. 184].

The ' germ ' of the second right upper true molar, Slades Green, British Museum (Nat. Hist.) 23717, purchased 1849. Figured by Leith Adams [**31,** pl. II, g. 1]. Adams stated that Slades Green is in Essex, but judging from similar errors he lacked a gazetteer. There is only one other specimen known, a molar in the Geological Museum still bearing Falconer's label of *Loxodon*, though it is not mentioned in his published MS. notes [**15**]. It is not represented in the W. B. Dawkins' Collection in the Manchester Museum, yet he has stated that this species was found abundantly at Crayford [**10,** p. xxxv]. This error was copied by A. Rutot in 1903 [**66,** p. 70], to the great detriment of his conclusions. It is probable that these three specimens came from the Crayford gravel and the locality of Slades Green supports this view. In the past fossils found their way to the nearest market. Many years ago Waggon's Pit, Aylesford, was famous for its Palaeolithic implements, and was visited by collectors. By an error, the neighbouring New Hythe pit acquired the reputation of being barren so all the New Hythe implements were " passed on " and sold at Waggon's pit. Something of this kind may well have happened at Crayford, for bones are abundant in the brickearth, but extremely rare in the gravel. The occurrence of *antiquus* in the brickearth is very doubtful. First record, Falconer and Cautley, 1845-9 [**4**].

Elephas primigenius Blumenbach. Common. Many specimens in British Museum (Nat. Hist.) and Geological Museum, and in the Manchester Museum.

Four tusks, presumably of this species, were exposed at the same time in Rutter's New Pit (E.) in 1894.

Figured specimen : left lower second true molar. L. Adams [**31**, p. 106, Pl. XII, f. 1], Geol. Mus., 7373.

Recorded specimens : Portion of lower jaw showing two last milk molars L. Adams [**31**, p. 96]. Geological Museum. Upper molar. L. Adams [**31**, p. 104]. Geological Museum, 158. Mandible in British Museum showing two teeth from Erith. L. Adams [**31**, p. 107]. Number seven molar from Crayford in Woodwardian Museum, Cambridge. L. Adams [**31**, p. 111].

" A mandible No. 624a in the Museum of the Royal College of Surgeons, England, from the brickearths of Grantham near Crayford below London," described by L. Adams [**31**, p. 111]. This is the specimen referred to by J. Morris. " A fine example of the lower jaw and teeth of the *Elephas primigenius* which Mr. Grantham has since most liberally presented to the Hunterian Museum " [7]. Adams has muddled his notes and changed the donors name to the locality of origin. Whether this specimen has survived enemy action I cannot say. Entire fibula of mammoth. L. Adams [**31**, p. 169]. British Museum (Nat. Hist.) M5107 (Spurrell Coll.).

Two patella. L. Adams [**31**, p. 167]. Geological Museum 4927, 4928. This species also occurred in the railway cutting (Dartford Loop). No animal has been the cause of so much wishful thinking as the Mammoth. In a paper read before the Geological Society, June 3, 1857, Falconer made the following remark, " The very name of *Elephas primigenius* was suggestive of ' transported gravel,' ' diluvial action,' ' glacial drift,' or some other explanation suggested by the image of the Woolly Mammoth,frozen in, flesh and bone, at the mouth of the Lena ; so that every stratum in which elephant bones were met with was regarded in some degree under the influence of a foregone conclusion." Numerous instances might be cited of the force of this bias upon the views of some of the ablest writers on the geology of the later Tertiary deposits " [**15**, vol. ii, pp. 78-9]. This bias still exists and today it is still maintained that its presence indicates a " bleak " climate. No man knew more about elephants than Falconer and he states " his constitutional flexibility was like that of man capable of adaptation to very great differences in climate " [**15**, vol. ii, p. 289]. The mammoth was a Holarctic species and since its nearest ally is the Indian Elephant, a tropical form, it is not surprising that its range extended south to Italy. Its range was probably determined by its food and this, in Siberia, was apparently in the main fircones and branches of conifers, though it was varied with grasses, mosses and meadow plants like Wild Thyme and Buttercup [**94a**, p. 143]. Tree branches were essential for the wear of its teeth. Bassett Digby has noted that an alder tree (*Alnus fructicosa*) 90 feet long occurred with it in Siberia [**94a**, p. 151]. It is probable that it fed on most trees and that the presence of conifers *only* in its stomach may have been due to the absence in the neighbourhood of other trees. It is certainly not a Steppe form, for it would be starved[1] to death on the present-day steppes and it is doubtful if it could survive an English winter with heavy snow. At the cold stage of Ponder's End, where the Mammoth was fairly common, there was certainly an abundant scrub growth. Ponder's End was a swamp where few trees if any could live, but there may well have been woodland on the higher ground.

The mammoth was common at Ilford and no one has suggested cold conditions for that deposit. Owing to its great adaptibility its presence is of little value in determining the former temperature, but one can infer that there was either an abundant woodland or scrub to provide the food for the herds of Mammoth found at Crayford. First record, J. Morris, 1838 [7].

[1] In the London papers of January 15th, 1943, it was stated that the military authorities had been considering the use of Elephants for transport in Burma, but " they eat too much."

Ovibos spurrelli sp. nov. The Ovibos from Crayford is certainly not *moschatus* Zim., and the differences have been described by W. B. Dawkins [**21**]. Hence, all deductions based on this presumed identity must be discarded. Very rare at Crayford and only known from a skull and four associated teeth. The skull was found by W. B. Dawkins and F. C. J. Spurrell in Stoneham's pit and described and figured by the former [**4**, Pl. i, f. 1, Pl. II, III, IV]. Original in Geological Museum (53444). The first flint artefact found in situ by the Rev. O. Fisher in 1872 came from the same level. This skull is the type of the species. The four associated teeth were obtained in 1879 by R. W. Cheadle from the same pit, but at a slightly higher level. When found the teeth were in the jaw, but this could not be preserved. Described by W. Davis, 1879 [**32**] and figured by S. H. Reynolds, 1934 [**105**, Pl. III., Figs. 3, 4 5]. In British Museum (Nat. Hist.) 50099.

Of the ecology of the Crayford *Ovibos* we know only what can be deduced from the associated species and since it is so rare its presence is of little importance. As S. H. Reynolds states, " It is quite possible that in former times Musk Oxen could thrive in a climate far more genial than those of countries to which at the present day they are restricted " [**105**, p. 11]. It is certain that in North America Musk Oxen had a far more extended range formerly than today, and it is very probable that its present restricted range is due to man. It has been considered advisable to give a new trivial name to the Crayford Musk-Ox, for although it is possible that it may be identical with one of several species described from the Continent, yet until this has been demonstrated it is better to use a new name rather than persist in using what is an obvious misidentification, with all that it implies. First record, W. B. Dawkins, 1872 [**21**].

Rhinoceros antiquitatis Blumenbach. Very common. Many specimens in British Museum (Nat. Hist.) and Geological Museum and in the Manchester Museum (Boyd Dawkins Coll.). It is probable that nearly all the skeletal remains of *Rhinoceros* from Crayford belong to this species. It was a very adaptable species, but it did require a very large amount of vegetable food and so this must have existed in the vicinity. The presence of this species affords no clue as to the temperature. This species is absent from all the Early Pleistocene deposits, making its first appearance in the Thames Valley at Ilford, where it is very rare. First record, W. B. Dawkins, 1867 [**14**].

Rhinoceros hemitoechus Falconer. Very rare. Four associated teeth in the Geological Museum ; in the British Museum (Nat. Hist.) there are three teeth, M5129, M5116, M5119. It would thus appear that this species was dying out in the Crayford stage. It was common at Ilford, Grays and Clacton, and is usually associated with *Hippotamus* and *Elephas antiquus*. *R. hemitoechus* in its recorded range is rather a southern form and like all the species of this genus required abundant food. First record, W. B. Dawkins, 1867 [**14**].

Rhinoceros megarhinus Christol. The recorded presence of this species in the Crayford brickearth has been the cause of much trouble, and Falconer's notes on it have been overlooked. He states : " Notes on remains of *R. leptorhinus* (i.e., *megarhinus*) in Dr. Spurrell's Coll. at Belvedere. There are four detached upper molars and he thought that their mineral condition differed from those of *R. antiquitatis* from the same beds. Prestwich thought some of the latter were similar, but admitted it was a case for enquiry " [**15**, vol. ii, p. 398]. " In Mr. Grantham's collection one molar of *R. leptorhinus* (i.e. *megarhinus*) very like Dr. Spurrell's [**15**, vol. ii, p. 398]. " Fourteen upper molars of *R. antiquitatis* in coll. Dr. F. Spurrell. They are in a ruder state and appear to have been rolled or tumbled about much more than the leptorhine (i.e. margarhine) molars in the same coll. (S.P.). Woodward, Prestwich and myself are agreed upon this " [**15**, vol. ii, p. 401]. Mr. Grantham's specimen has not been traced, but the four in the Spurrell Collection are now in the British Museum (Nat. Hist.), M5131, M5132. It is obvious that Dr. Spurrell had not collected the specimens himself, but that they had been brought to him. In appearance these teeth are quite unlike anything that I have seen from Crayford. They exhibit no trace of rolling and are very dark in colour. One would infer that they came from a bed of peaty clay. The evidence for their Crayford origin is the workman's word, alas too often unreliable. In the past when collectors restricted their collecting to certain areas, it was a temptation to a workman to give a wrong locality.[1] There is one tooth (IM3) in the Manchester Museum (W. B. Dawkins Coll.). Dr. J. W. Jackson informs me that it is light coloured, so it cannot be Mr. Grantham's specimen. This requires examination. The record of *R. megarhinus* from Crayford was rejected by M. A. C. Hinton in 1926 [**94**], and the evidence is so unsatisfactory that it is better to adopt this course. It is curious that no examples of the species have been recorded from Crayford since the brickyards at Grays closed down, where it was common. First record, J. Morris, 1858 [**7**], as *R. leptorhinus* on the authority of Falconer.

Citillus erythrogenoides (Falconer). Specimens in the British Museum (Nat. Hist.) and Geological Museum. Common in Rutter's new pit (W.). Fragmentary remains occurred in the *Corbicula* Bed at Stoneham's, showing that its presence is not due to later burrowing ; an extinct species of whose ecology we know nothing though its allies are certainly grassland forms. First record, R. W. Cheadle, 1876 [**28**], "*spermophilus* sp. from Erith."

Lepus sp. A lower jaw in Geological Museum (62861) from the *Corbicula* Bed at Stoneham's. The genus is new for Crayford, but the specific determination must be left to the future.

Microtus sp., approaching *M. anglicus*, Hinton. First record, M. A. C. Hinton, 1910 [**75**, pp. 493-4].

Microtus nivalis Martins. Not uncommon in both Stoneham's and Rutter's new pit (E.). M. A. C. Hinton figured and described nine teeth in 1907 [**71**, p. 47, Pl. I., pp. 6-14]. Of these, Fig. 12 is in the Geological Museum (6018). These were referred later to the *nivalis* group, and the original figures reproduced [**93**, p. 131]. First record, M. A. C. Hinton, 1907 [**71**].

Microtus ratticeps (Keyserling and Blasius). Occurred in Stoneham's and common in Rutter's new pit (E.). It was first found at Erith [**46**, p. 454]. Two teeth figured by E. T. Newton from Erith and Crayford in 1890 [**46**, p. 454]. In Geological Museum (5643, 3085). First record, E. T. Newton, 1889, in W. Whitaker [**44**, p. 336].

Microtus malei Hinton. Not uncommon in Stoneham's and Rutter's new pit (E.). Sixteen teeth figured and referred to this and allied forms in 1926 [**93**, pp. 132-3]. First record, M. A. C. Hinton, 1926, as above.

M. A. C. Hinton has also figured a palate with teeth of *Microtus* sp. from Crayford [**93**, Pl. I.].

Dicrostonyx gulielmi Sandford. Very rare. M. A. C. Hinton states : "Part of a skull and mandible collected by Mr. F. C. J. Spurrell described and figured, under the name *Myodes torquatus*, by Mr. E. T. Newton (*Geol. Mag.* (3), 7, 1890, p. 454, Figs. 3-6). Re-examined and determined as *D. gulielmi* by the writer ; this record supports the opinion that the Fisherton remains are to be referred to *D. gullielmi*, because in other respects the fauna of the Fisherton Brickearth is closely similar to that obtained at Erith " [**93**, p. 162]. This, the only known specimen, is in the Geological Museum (5641). First record, E. T. Newton, 1890 [**46**].

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[1] A late bronze spearhead, part of the hoard dredged off Broadness near Northfleet, was eventually purchased by a collector of London antiquities from a navvy who stated that he had found it at a depth of fifteen feet at Cornhill, but the evidence of its origin was still on it.

Lemmus lemmus (Linné). Rather rare. Specimens described and figured by E. T. Newton in 1890 [**46**] and now in Geological Museum (5640). M. A. C. Hinton states : " Some fragmentary jaws in the Spurrell collection from Erith and several detached teeth in various private collections from Crayford " [**93**, p. 196]. These latter came from Stoneham's and Rutter's new pit (E.). First record, E. T. Newton, 1890 [**46**].

The microtine faunule of Crayford is a well-marked one. M. A. C. Hinton states : " Between Early (Grays Thurrock) and late Middle Terrace (Crayford) times the Microtinae, together with most of the other mammals of Britain, were completely changed. Old forms, surviving in a more or less modified condition from the Pliocene period, now became extinct and were replaced by an entirely new assemblage." " Just how many species should be recognized among the voles listed as members of the *M. nivalis* group " and " *M. malei* and allies " is difficult to say ; but these forms are strongly marked and especially characteristic of this horizon " [**93**, pp. 132-3].

Though called a " northern group " this term was not used to imply colder conditions, but merely that their present representatives are most abundant in the North. Their present distribution is probably due to other factors than temperature, just as it is with *Elephas*, *Felis* and *Hyaena*.

(c.) Mammalia recorded in error.

Ursus spelaeus Rosen. Dawkins, 1867 [**12**].
Ursus horribilis Ord. Newton in Woodward, 1890 [**48**].
Rangifer tarandus (Linné) recorded as very doubtful. Falconer, 1868 [**15**, vol. ii., p. 478].
Rhinoceros megarhinus Christol. Dawkins, 1867 [**12**].
Hippopotamus major Cuvier Dollfus, 1884 [**39**].
Bos longifrons Owen. Dollfus, 1884 [**39**].
Microtus agrestis (Linné). Woodward and Sherborn, 1890 [**47**].
„ *amphibius* (Linné). Owen, 1844 [**3**].

The references are to the first record. The errors of Dollfus in recording *H. major* and *B. longifrons* are difficult to explain. A reference to Whitaker is given, but it is wrong. The work cited does not deal with Crayford and the names do not occur on the page quoted. These errors have not found their way into English literature, but have been repeated in Continental works.

(d.) Aves.

Anser sp. Fragmentary bone in Geological Museum determined by E. T. Newton. First record, Hinton and Kennard, 1900 [**56**]. Fragments of egg shells were found in the *Corbicula* Bed in Rutter's new pit (E.) by the author.

(e.) Batrachia.

Rana temporaria Linné (Frog). Very rare. Geological Museum, named by E. T. Newton.

(f.) Pisces.

Esox lucius Linné (Pike). Specimens in British Museum (Nat. Hist.) and Geological Museum. First record, E. T. Newton, 1901 [**61**]. Judging from the abundance of the molluscs *Psilunio* and *Anodonta* other fish were present, for the Glochidium stage of these bivalves is passed in the gills of fish ; in the case of *Anodonta*, " Sticklebacks " are said to be the host, but I have been unable to ascertain which of the two species (now placed in different genera).

(g.) Conclusions drawn from Vertebrate Fauna.

The Crayford mammalian faunule is a mixed one, including both woodland and open-country species, and this probably reflects the conditions of the surrounding country. This has been termed 'park land,' but unlike our modern parks where the lower branches of the trees have been eaten off only as high as the deer can reach, the additional factor of the larger herbivores must be considered and their reach is much higher. Hence it is probable that there is nothing comparable in Europe today. All the species are well developed and in the case of *Cervus elaphus* and *Felis spelaea*, they attain gigantic size, which they certainly would not under the adverse conditions of cold climate. The faunule as a whole denotes warm temperate conditions, probably warmer than today. One is tempted to suggest rather warmer winters with but little snow, otherwise the larger herbivores would have starved to death. There is a strong probability that many of the bones in the Lower Brickearth are food debris. We know that there were human settlements on the banks and the jaw of *Rhinoceros antiquitatis* noted by F. C. J. Spurrell [**35**, p. 546, Pl. 7] was certainly brought there by human agency and not by stream action. It is thus probable that the apparent mixture of woodland and open-country forms does not reflect accurately the condition of the nearby country, for the animal remains may have been brought from some distance where different conditions existed. There is no evidence that any of the mammals were mired. It is difficult to explain the abundance of the smaller vertebrata in the *Corbicula* Bed. In caves one can justly presume the presence of birds of prey with their "castings." Falconer has, however, noted: "In India in the tanks or wherever running water falls into an artificial lake, numerous remains may be observed, along the margin of the bones of frogs, lizards, mice and muskrats forming a more or less continuous edging without the admixture of large bones which lie in abundance below the deeper water. The former float and are drifted to the margin by the action of the wind and rest there. M. Lartet pointed out to me in the rich Falunian deposit of Seissan (i.e. Sansan) certain parts of the lacustrine bed where skeletons of large terrestrial animals such as *Mastodon* and *Rhinoceros* are more or less abundant; whilst in other situations near the margin immense quantities occur of the bones of small animals such as frogs, lizards, shrews and minute rodents which may be taken up by the handful unmixed with larger bones" [**15**, vol. ii, pp. 428-9]. This is a possible explanation, though I have never seen anything like it in England, possibly because the smaller vertebrata are rare.

M. A. C. Hinton has stated with regard to the microtine fauna of Crayford: "Old forms surviving in a more or less modified condition from the Pliocene period now became extinct and were replaced by an entirely new assemblage" [**93**, p. 131]. The evidence from the larger mammals is rather different. *Ovibos* is the only newcomer, and *Rhinoceros hemitaechus* Falc. makes its last appearance. *Elephas primigenius* Blüm and *Rhinoceros antiquitatis* Blüm., the two characteristic late Pleistocene forms, first appear at Ilford. It is obvious that the larger forms have greater powers of locomotion than the smaller, hence the difference.

IV. PLANT REMAINS.

The presence of large numbers of the great herbivorous mammals shows that there must have been an abundance of their food, but only one plant has been recorded from the Crayford Brickearths, the Sweet Chestnut *Castanea sativa* (Mill), by H. N. Ridley [**41**]. This, in the form of wood, was found in the lowest part of the brickearth, together with palaeolithic flakes, during an excursion of the Geologists' Association in 1885 (*Proc. Geol. Assoc.*, vol. ix, pp. 215-216). This identification has been challenged on the ground that it is extremely difficult to tell the difference between the woods of *Castanea sativa* and *Quercus sessiliflora* [**74**, p. 37]. A. J. Wilmott has expressed to me his opinion that the record is doubtful and that a re-examination of the material, if it exists, should be made. There is no inherent improbability in the record of *Castanea sativa*, for the accompanying mollusc *Psilunio littoralis* (Cuvier) is, like *Castanea*, a southern form and abundant in Spain. In any case neither the oak nor the chestnut lives within the influence of glacial conditions.

V. FLINT IMPLEMENTS.

The Rev. O. Fisher was the first to find and record a human artefact at Crayford in 1872 and he found it *in situ* [**23**]. This was in Stoneham's pit, though the finder called the locality " Slades Green," and this mis-naming has caused trouble as to its provenance. The flake was in the same bed as the *Ovibos* skull, as noted by W. B. Dawkins, who was present at the discovery [**25**]. In spite of all the facts there was a bitter controversy (which is now forgotten), for " there is no pain so great as the pain of a new idea." In 1876 R. W. Cheadle described and figured a second example which he had found, also *in situ*, two inches above the *Corbicula* Bed at Erith [**30**, p. 96] ; the figure was reproduced by W. B. Dawkins in 1880 [**34**, p. 136, f. 27]. This specimen is in the British Museum (Nat. Hist.), E212. Sir John Evans has noted that a large broad flake was picked up in a brickearth pit at Erith by Dr. J. H. Gladstone (father-in-law of the late Prime Minister, Ramsay Macdonald) and recorded in *Brit. Assoc. Report*, 1875 (1876), *Nature*, vol. xii, p. 202, *Proc. W. London Scient. Assoc.*, 1876, and figured in the *Argonaut*, September, 1875, p. 263 [**54**]. I have been unable to verify the two last references. In 1880 F. C. J. Spurrell described the working-floor at the foot of the chalk cliff in Stoneham's pit, figuring a restored block (see Pl. 7B) and a flake. These are now in the British Museum (Nat. Hist.), E249, E249a. The latter specimen is now removed from the matrix on which it was figured. The jaw of *Rhinoceros antiquitatis* with flint flakes resting on it, noted by F. C. J. Spurrell [**35**, p. 546] and now in the British Museum (Nat. Hist.), E254, is the subject of a postcard issued by that institution (see Pl. 7A). In the same year, but probably later, the same author published a very similar account in the *Archaeological Journal* with two plates and one text figure [**35a**]. Of the figured specimens Pl. I. is the large restored block noted above ; British Museum (Nat. Hist.), E249. Pl. II, Fig. 1, small restored block ; British Museum (Nat. Hist.), E250. Fig. 2, long flake 5 x 1.5 inches, in British Museum (Nat. Hist.) ; and short flake 4.1 x 1.6 inches, in British Museum (Nat. Hist.) ; the two specimens not yet isolated. Fig. 3, core from the large restoration, British Museum (Nat. Hist.), E1013. Text figure (p. 295), hammer stone, British Museum (Nat. Hist.), E992. In 1882 another paper came from the same pen [**35b**], but I have been unable to trace the existence of any copy. This paper was followed in the next year by an extended account of the working floor, describing methods apparently employed for flaking and figuring the same hammer stone as in **35a** [**37a**]. A resumé of Spurrell's finds also appeared in the same year [**37b**] and additional information in 1886 [**42**].

W. Whitaker in 1889 was the author of a brilliant summary of the knowledge of palaeolithic implements in the Lower Thames Valley [**44**, pp. 338-352]. In 1901 J. P. Johnson figured two flakes from Crayford [**59**] and reproduced the figures in 1902 [**64**]. M. A. C. Hinton and A. S. Kennard in 1905 claimed that the implements were Mousterian [**67**], but typology was then in its infancy and the use of this term, though correct at the time, is misleading in the light of our present knowledge. The same opinion was adopted in 1914 by R. Brice Higgins in his account of the Crayford artifacts [**80**]. In 1916 R. H. Chandler described and figured flakes and cores from Rutter's new pit (W.), and rightfully stated they were not true Mousterian [**84**]. More recently they have been assigned to the typological stage of Levallois III of Breuil [**101**, p. 17]. But the subject is complicated by the fact that hand axes do occur. There is a fine example in the British Museum (Nat. Hist.) (ex G. F. Lawrence Coll.), Fig. **14**. This is labelled "Brickearth Crayford," and from its condition the label is probably correct. A. D. Lacaille has informed Dr. K. P. Oakley that there are several in the Welcome Museum ex Coll. W. M. Newton, of Dartford, a well-known collector who for many years had the pick of the various antiquities found in the neighbourhood.

Hence a re-examination of all the material is needed before a satisfactory conclusion can be reached, and under present conditions this cannot be done. Judging from what I have seen at Swanscomb, the typological scale may be at fault. Of particular interest is the statement that the artifacts are abundant on top of the Crayford gravel [**84**], thus proving the existence of a land-surface at this level. F. C. J. Spurrell in 1886 stated that the implements from the gravel were of an older type than those from the brickearth [**42**, p. 25], and one specimen is in the British Museum (Nat. Hist.), E1003. (See Fig. 15). This is stated to be from "The Gravel, the Gardens, Erith," a locality I have been unable to trace. It is a fine example of the so-called "cleaver," a type that occurs in the older middle gravel at Swanscomb, but is very rare.

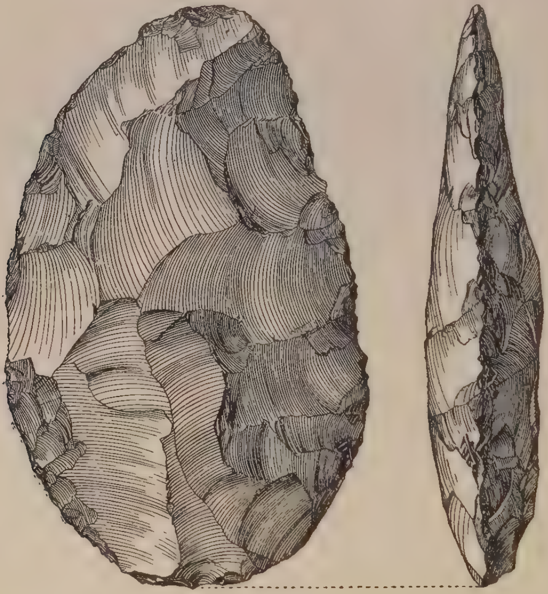
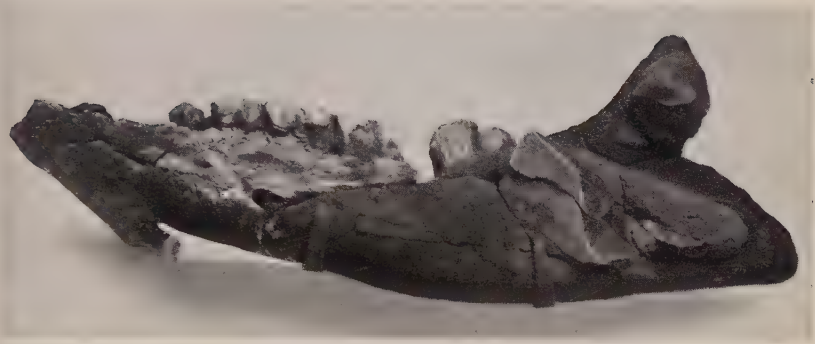


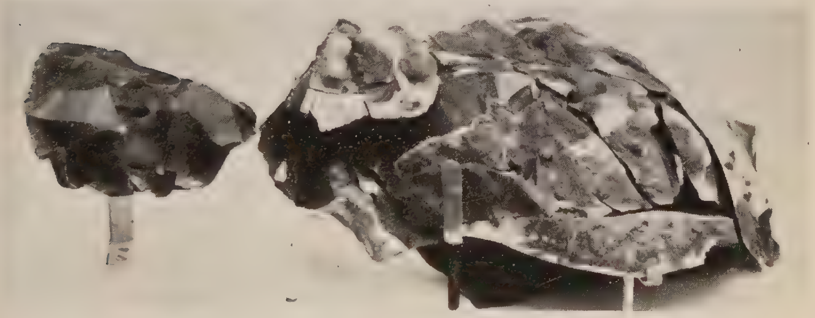
FIG. 14.

Thin foliate hand-axe. Unrolled. Flint with patina of 'basket-work' type (mottled buff and bluish), passing into uniform yellowish-buff on one face. Acheulio-Levalloisian industry. From Brickearth, Crayford. Dr. C. T. Trechmann's Coll. (ex G. F. Lawrence Coll.). (*Half nat. size. del. C. O. Waterhouse*).

The artifacts certainly occurred in most of the pits, probably in all. It has recently been stated that "a floor of implements occurs at the base of the brickearth at Crayford; they do not appear to have been found at higher levels in the deposit" [**113**, p. 44]. This is not correct. The working-floor at the base is a well established fact, but the artifacts occur at all levels in the Lower Brickearth The first one *in situ* was six feet above the base [**23**], and the second at a much higher level, two inches above the *Corbicula* Bed [**30**]. The only one I found was eight feet above the floor, in Rutter's new pit (E.). The



A.—Portions of lower jaw of *Rhinoceros antiquitatis* Blum. found broken on a heap of flint flakes, several of which (grey, unpatinated) are seen adhering to it. From Levalloisian ' floor ' at base of Lower Brickearth, Stoneham's Pit, Crayford. Spurrell Coll., Brit. Mus. (Nat. Hist.), E. 254. [*About ½ natural size, laterally inverted.*]



B.—*Right :* Flint nodule reconstructed from the waste flakes removed in the preparation of a core for the production of flake-tools. *Left:* Prepared core which formed the centre of the adjacent mass of re-united flakes. From Levalloisian ' floor ' at base of Lower Brickearth, Stoneham's Pit, Crayford. Spurrell Coll., Brit. Mus. (Nat. Hist.), E. 249 (nodule), E. 1013 (core). [*About ½ natural size, laterally inverted.*]

Figures A and B are reproduced by the kindness of the Trustees of the British Museum.

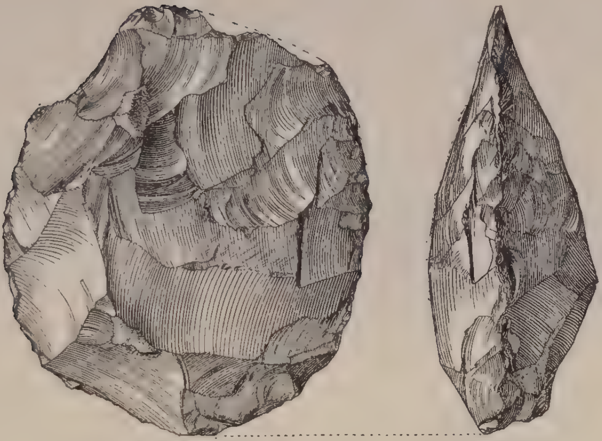


FIG. 15.

Hand-axe with oblique cleaver edge. Slightly rolled ; several damage chips at edges. Dark grey flint with thin patina and deep ochreous staining. Damage chips barely patinated ; unstained. Late-Middle Acheulian industry. From Crayford Gravel, Erith Gardens. Spurrell Coll. Brit. Mus. (Nat. Hist.), E.1003. (*Half nat. size. del. C. O. Waterhouse*).

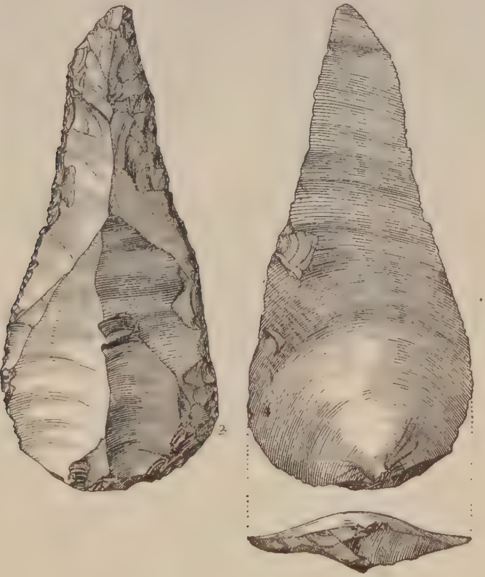


FIG. 16.

Pointed flint blade with sub-faceted butt. A dual purpose tool ; shows fine secondary work on either side of tip, and on marginal swelling (*a*) near base. Lustrous black flint ; unpatinated. Levelloisian industry. From Brickearth, Crayford. Spurrell Coll. Brit. Mus. (Nat. Hist.), E.1004 (*Half nat. size. del. C. O. Waterhouse*).

workmen said they occurred at all levels and I know no reason to doubt their statement. My experience is that workmen are reliable when dealing with broad facts, but unreliable in details regarding individual specimens. As a rule the artifacts are unpatinated, but they are sometimes white and I have seen one, white on one side and unpatinated on the other (Corner Coll.). They are usually long, rather narrow and taper to a point and have been struck from a prepared core as first noted by F. C. J. Spurrell [**37a**]. Sometimes they are retouched on the flat side at the apex, showing that a sharp point was the object required and thus contrasting with those found at Ebbsfleet, which are usually oval. I am indebted to Dr. K. P. Oakley for pointing out that both the Crayford and Ebbsfleet types are represented in the Spurrell Collection from the tramway cutting at Ebbsfleet. There is no clue as to their stratigraphical positions and it may well be that the two types are not of the same age, though resting on the same bench. He also informed me that there are eight large flakes in the Sturge Collection at the British Museum, Bloomsbury. Two typical flake implements from Crayford are figured (Figs. 16, 17).

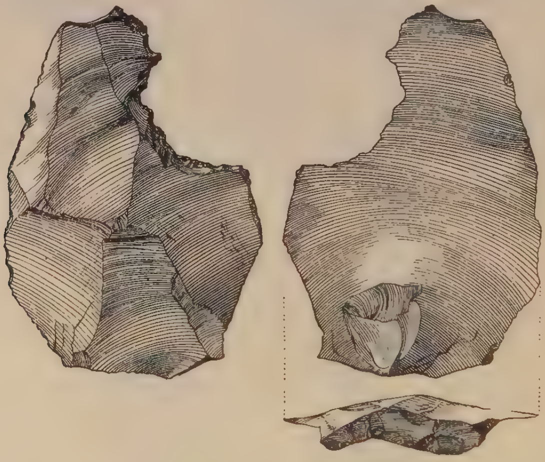


FIG. 17.

Oval flake-tool with faceted butt and chipped hollow produced by (or for) some specialized use. Grey flint with mottled bluish to buff patina (showing tendency to 'basket-work' type). Levalloisian industry. From Brickearth, Crayford. Spurrell Coll. Brit. Mus. (Nat. Hist.), E.258. (*Half nat. size. del. C. O. Waterhouse*).

When I first visited the pits in 1892 it was clear that the men were well acquainted with "spear heads," as they called them, and soon produced a number from their pockets. In 1895, whilst sieving sand in Rutter's new pit (E.), I was accosted by two navvies, who certainly did not work there. They offered me a fine series of forgeries made by John Gibbs, but having been initiated into forgeries by the late Dr. Frank Corner, I was not a buyer. John Gibbs had been a lodger with the notorious George Glover, better known as "Nobby" and had learnt from him the art of making forgeries, and the pupil was as good as the master. There was a "gentleman's" agreement between them that the master would confine his activities to the north of the river, and the pupil to the south. However, one day Glover bought from another navvy a polished axe made by Gibbs, mistaking it for a genuine implement, and a feud ensued. Gibbs lived for some years at Woolwich and there were good examples probably of his work in the Spurrell Collection when it was received by the British Museum (Nat. Hist.) in 1895. These included a polished axe and a flint knife recorded as having been found in a " dugout " canoe in the Erith marshes (*Arch. Journ.*, vol. xiii, 1885, p. 302 note). Both were clever forgeries. These forgers have been dead for some years and flint implements are now so common that in the absence of rich collectors there is no longer an incentive to make them.

VI. MOLLUSCAN FAUNA.

(a.) General.

Crayford was easy of access from London, the shells were well preserved and abundant, whilst the sections were ' permanent ' and were worked until well into this century (C. 1913). Hence extensive collections were made and there is a large amount of material available, contrasting in this respect with the much richer beds of Ilford and Grays, which were closed down (except for temporary sections) much earlier, and so did not receive the attention of the enthusiastic fossil collectors of late Victorian times. The literature relating to this branch of palaeontology is extensive, but the growth of knowledge necessitates periodical revisions so an attempt has been made to bring it up to date. The Crayford faunule is not an isolated one, but forms part of the English Pleistocene complex. Its ancestry is to be found in earlier beds and its descendants are living here today. Moreover, the English Pleistocene complex is also a part of the Continental one, and so one has to study this also before one can appraise its value correctly. Thanks to many Continental workers, especially the Abbe H. Breuil, I have been able to examine a very large amount of Continental material and it is clear that there have been many mis-identifications in the past and needless creations of species. To rely on Continental literature alone is to build on running sand, but with the material before you it is another matter.

The following list contains the names of the species known from the Crayford Brickearths, but they are not listed systematically, but divided according to habitat into land and freshwater. Systematics are of secondary importance to geologists. What they wish to know is not the relations *inter se* of the various species, but what ecological conditions can be deduced from their presence or absence. In a fluvatile deposit one can hope to get the greater part of the freshwater forms though varying loci may be represented, but the presence of land shells is a matter of chance due to flooding. The list contains 52 species from Crayford and the list from the Loop cutting west of Dartford is given separately. This includes two land forms not known from Crayford, though the two deposits are probably of the same age. The first recorder and date are given, though it must be remembered that Alfred Bell was responsible for A. Tylor's list [**19**]. All the shells are probably contemporary and not derived from older beds, though many loci are represented.

(b.) Species from Crayford Brickearths.

FRESHWATER SPECIES.

Bithynia tentaculata (Linné) J. Morris 1838 [**1**.]
„ *inflata* Hansen B. B. Woodward 1890 [**48**].
Viviparus fasciatus (Müller) W. B. Dawkins 1867 [**12**].
Valvata piscinalis (Müller) W. B. Dawkins 1867 [**12**].
„ *cristata* Müller A. Tylor 1869 [**19**].
Paladilihia radigueli (Bourguignat). B. B. Woodward 1890 [**48**].
Lymnaea peregra (Müller). W. B. Dawkins 1867 [**12**].
„ *palustris* (Müller). A. Tylor 1869 [**19**].
„ *truncatula* (Müller). A. Tylor 1869 [**19**].
„ *stagnalis* (Linné). W. B. Dawkins 1867 [**12**].

Planorbis corneus (Linné). J. Morris 1838 [**1**].
„ *albus* Müller. R. W. Cheadle and B. B. Woodward 1876 [30].
„ *laevis* Alder. B. B. Woodward 1890 [**48**].
„ *crista* (Linné). B. B. Woodward 1890 [**48**].
„ *planorbis* (Linné). J. Morris 1838 [**1**].
„ *vortex* (Linné). J. Morris 1838 [**1**].
„ *leucostoma* Millet. A. Tylor 1869 [**19**].
„ *vorticulus* Troschel.
„ *contortus* (Linné). B. B. Woodward 1890 [**48**].
Segmentina nitida (Müller). B. B. Woodward 1890 [**48**].
„ *complanata* (Linné).
Ancylastrum fluviatile (Müller). W. B. Dawkins 1867 [**12**].
Ancylus lacustris (Linné). B. B. Woodward 1890 [**48**].
Psilunio littoralis (Cuvier). J. Morris 1838 [**1**].
Anodonta cygnaea (Linné). W. B. Dawkins 1867 [**12**].
„ *anatina* (Linné).
„ *minima* Millet.
Sphaerium corneum (Linné). W. B. Dawkins 1867 [**12**].
„ *dickinii* Clessin. G. F. Dollfus 1884 [**39**].
Corbicula fluminalis (Müller). J. Morris 1838 [**1**].
Pisidium amnicum (Müller). J. Morris 1838 [**1**].
„ *sulcatum* S. V. Wood. B. B. Woodward 1890 [**48**].
„ *cinereum* Alder. B. B. Woodward 1913 [**78**].
„ *nitidum* Jenyns. A. S. Kennard and B. B. Woodward 1901 [**60**].
„ *milium* Held. B. B. Woodward 1913 [**78**].
„ *subtruncatum* Malm. B. B. Woodward 1913 [**78**].
„ *henslowanum* (Sheppard). G. F. Dolfuss 1884 [**39**].
„ *lilljeborgi* Clessin. B. B. Woodward 1913 [**78**].
„ *supinum* A. Schmidt. A. S. Kennard and B. B. Woodward 1905 [**68**].
„ *moitessierianum* Paladilhe. A. W. Stelfox 1918 [**86**].

LAND SPECIES.

Pupilla muscorum (Linné). J. Morris 1838 [**1**].
Vallonia pulchella (Müller).[1]
„ *excentrica* Sterki.
„ *costata* (Müller).
Zua lubrica (Müller). B. B. Woodward 1890 [**48**].
Limax sp.
Candidula radigueli (Bourguignat). W. B. Dawkins 1867 [**12**].
Trochulus hispidus (Linné). J. Morris 1838 [**1**].
Cepaea nemoralis (Linné). W. B. Dawkins 1867 [**12**].
Cecilioides acicula (Müller). A. S. Kennard and B. B. Woodward 1901 [**60**].
Succinea pfeifferi Rossmässler. R. W. Cheadle and B. B. Woodward 1876 [**30**]
„ *oblonga* Draparnaud. R. W. Cheadle and B. B. Woodward 1876 [**30**].

There are five new records in the above list.

(c.) Species from Brickearths in Railway Cutting (Dartford Loop).

FRESHWATER SPECIES.

Valvata piscinalis (Müller).
Bithynia tentaculata (Linné).
Lymnaea stagnalis (Linné).
Planorbis corneus (Linné).
„ *planorbis* (Linné).
„ *leucostoma* Millet.
Pisidium amnicum (Müller).

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[1] *Vallonia puchella* (Müller) of the older writers was an aggregate, so one cannot say which of the three species was before them.

LAND SPECIES.

Zua lubrica (Müller).
Arianta arbustorum (Linné).
Clausilia rugosa (Draparnaud).

The two last species are not known from the Crayford deposits, though usually included in the Crayford list. So far as they go, and the list from the cutting is a small one, the mollusca support the view that the two deposits are of the same age. All the above have been verified principally from examples in my collection given by W. Whitaker.

(d.) Species recorded from Crayford in error.

Littorina rudis (Maton). A. S. Kennard 1895 [**52**] = apical fragments of *Viviparus fasciatus* (Müller). There is no evidence of proximity of marine conditions.

Acme lineata. (Draparnaud). A. S. Kennard and B. B. Woodward 1901 [**60**]. Wrong locality, the containing box having been used previously for other material. *Fusus* sp. was also recorded from Erith through a similar occurrence (Woodward) [**48**, p. 377].

Viviparus viviparus (Linné). W. B. Dawkins 1867 [**12**] = *V. fasciatus* (Müller).

Valvata naticina Menke. A. S. Kennard and B. B. Woodward 1905 [**68**]. An abnormal *V. piscinalis* (Müller) *V. naticina* is only known from the High Terrace of Swanscomb (later beds) and the Cromerian of Sidestrand and Little Oakley.

Belgrandia marginata (Michaud). Tylor 1869 [**19**]. Probably a printer's error.

Carychium minimum Müller. J. Morris 1838 [**1**]. The *C. minimum* of older authors is an aggregate of *minimum* Müller and *tridentatum* (Risso). The original specimens are lost and no example of *Carychium* has been obtained since. It is possible that very young examples of *Lymnaea* were mistaken for *Carychium.*

Lymnaea auricularia (Linné). A. Tylor 1869 [**19**]. This species is not known from the English Pleistocene. Inflated forms of *L. peregra* (Müller) do occur and these are held to be the cause of the error.

Planorbis carinatus Müller. J. Morris 1838 [**1**]. An error for *P. planorbis* (Linné).

Planorbis dazuri Morch. C. L. F. Sandberger 1875 [**20**]. *P. leucostoma* Millet.

Planorbis arcticus Beck. A. S. Kennard and B. B. Woodward 1905 [**68**]. Identified by Dr. A. C. Johansen. The Crayford shells are probably ecotypes of *P. laevis* Alder.

Vitrea crystallina (Müller). A. Tylor 1869 [**19**], originally recorded with doubt. Probably a young *Vallonia.*

Retinella nitidula (Draparnaud). A. Tylor 1869 [**19**].

R. radiatula (Alder). A. Tylor 1869 [**19**]. These two records are probably printers' errors ; the asterisks being in the wrong column.

Pyramidula rupestris (Draparnaud). G. F. Dollfuss 1884 [**39**]. Probably a young *Vallonia.* This error only occurs in Continental literature.

Agriolimax agrestis (Linné). A. S. Kennard 1895 [**52**]. Now listed as *Limax* sp.

Monacha cantiana (Montagu).

Vortex lapicida (Linné). Both first recorded by R. W. Cheadle and B. B. Woodward 1876 [**30**] and withdrawn as " Top soilers," B. B. Woodward 1890 [**48**].

Succinea putris (Linné). A. Tylor 1869 [**19**]. This may well have occurred, for it is found in the High Terrace at Swanscomb, but the originals are lost and the species has not been found since.

Lymnium pictorum (Linné). A. Tylor 1869 [**19**]. Probably a printer's error.

Pisidium obtusale (Lamarck). G. F. Dollfus 1884 [**39**]. This species has never been found since, though very large series of *Pisidia* have been examined and in 1884 the criteria of the various species had not been fixed.

(e.) Notes on Species occurring at Crayford.

Whenever possible the number of specimens seen has been given. In nearly all cases this is an underestimate and refers to my own collecting. Nearly all the material was from the *Corbicula* Bed. The references to the Forest Bed of Little Oakley, Essex, are to an undescribed section at 60 ft. O.D. discovered by S. Hazzledine Warren.

Bithynia tentaculata (Linné). Abundant, 2,000 examples seen; well developed 12.5 mm. high. The shells from the Admiralty section (an exceptional deposit) are larger, those from Grays are smaller, whilst Uphall, Ilford and Barnwell specimens are the same size as Crayford ones. A Holarctic species. In the United States, where it is rare, it was formerly considered a recent introduction, but from its fossil occurrences there is a true native. Known from the Norwich Crag of Bramerton, Bulcamp and Southwold it is extremely rare in the Forest Bed (no examples known from W. Runton), where the next species, *B. inflata* Hansen, replaces it. Common in Pleistocene and Holocene deposits. Rather a southern form, its northern limit is the summer isotherm 14°. First record, J. Morris, 1838 [**1**].

Bithynia inflata Hansen. Rare, 55 examples seen, well developed, 9 mm. height. In the English Pleistocene it is not uncommon, whilst in the Holocene it is replaced by the smaller existing species, *B. leachii* (Sheppard). *B. inflata* is common in the Forest Bed of Norfolk and is also found at Little Oakley. Though extinct in England it still lives in Central Europe, its northern limit being the summer isotherm of 15°C. Apparently absent from the Pleistocene of France. First record, B. B. Woodward, 1890 [**48**].

Viviparus fasciatus (Müller). Rare. One adult specimen in British Museum (Nat. Hist.) 31 mm. Thirty apical fragments seen. This may possibly be identical with *V. menzelii* Franz from the Pleistocene of Germany [**95**, 107], but there are no specimens of this species in this country for comparison. *V. fasciatus* is a variable form, apparently according to its environment, and it is possible that *menzelii* is an ecotype. The history of the genus in the later Tertiaries of England is a good example of the imperfection of the Geological Record. *V. Medius* S. Woodward is known from the Red Crag, is common in the Norwich, and probably in the Weybourne Crag. *V. glacialis* S. V. Wood only occurs in the Weybourne Crag. *V. gibbus* Sandberger is abundant in the Forest Bed. The genus is absent from the older part of the Thames High Terrace, but in the later part *V. diluvianus* (Kunth) occurs in both Dierden's and Rickson's pits, Swanscomb, and at Clacton. The genus next appears at Crayford—the last record for the Pleistocene. Two species, *V. Viviparus* (Linné) and *V. fasciatus* (Müller), live in England today and occur though rarely in the Holocene. The genus is absent from the French Pleistocene, but occurs in the German Pleistocene. *V. fasciatus* is rather a southern form, its northern limit being the summer isotherm of 15-16°C. Its habitat is rather deep, slow-moving water. First record, W. B. Dawkins, 1867 [**12**].

Valvata piscinalis Müller. The most abundant form ; 10,000+ specimens seen. Very well developed and varying greatly, but as a rule of one type. Dr. O. Boettger said (*in litt*) that they were typical *piscinalis*, whilst Dr. A. C. Johansen said they were not, and should be named. This difference of opinion may have arisen from the fact that the former was well acquainted with German specimens and the latter with Danish. The *V. piscinalis* complex is a difficult question and there is no agreement amongst students at the present day. It is apparently influenced by its environment, the lake form *V. alpestris* Kuster being very different from the river or stream form *piscinalis* vera. Dr. Jules Favre has shown that Lake Geneva forms of this group vary according to their depth, the high-spired form *antiqua* Sow, but is probably not *antiqua* vera, being a deep-water form, but in English river deposits that are certainly shallow water, *Antiqua* vera is abundant. The sequence in England is as follows. In the Forest Bed of Norfolk and Suffolk and also at Little Oakley a smallish form occurs rather commonly. This has been named *V. andreana* Menzel by Dr. O. Boettger and it certainly agrees with paratypes of that species in my collection. In the older part of the Thames High Terrace there is a form rather rare which is near to *andreana*. In the later part, Valvatas of the *piscinalis* group occur by the million, but they are all *antiqua*, though there is no evidence of change in the ecology. These are equally abundant at Grays, their last appearance. At Uphalt, Ilford, *V. piscinalis* vera is rare, but from then to the present day it is the sole form. *V. piscinalis* has been recorded from the Norwich Crag, but judging from the figures given by S. V. Wood they are *andreana* Menzel and possibly *V. piscinaloides* Mich., known from the French Pliocene.

V. piscinalis is a Palaearctic species ranging north to summer isotherm of 8—10°C. Certainly prefers clean water. First record, W. B. Dawkins, 1867 [**12**].

Valvata cristata Müller. Not common ; 157 examples seen. The specimens are all small, this species apparently preferring muddy water. A Palaearctic species attaining its northern limit in the Orkneys, summer isotherm 13°C. In these islands its known range is from the Cromer Forest Bed to Recent. First record, A. Tylor, 1869 [**19**].

Paladilhia radigueli (Bourguignat). Very rare, only one specimen seen, in British Museum (Nat. Hist.). This can only be considered a provisional identification, for no authentic example from the French Pleistocene has been seen. The species is known from the Pleistocene of Swanscomb, Clacton, Grays, Ilford, Shoeburyness, Southchurch, Chislet, Stutton and West Wittering. *P. deani* (Kendall) is almost certainly the same, so Orton Waterville and Woodston can be added to this list. Though mainly a freshwater form, it could adapt itself to estuarine conditions. It is not known living, though closely allied forms occur in the south of Europe. Bourguignat, with his usual enthusiasm for naming every mutation, described several species from the French Pleistocene and he clearly had seen many specimens [**18**], but the genus was not represented in the material sent by the Abbé Breuil. It is probable that there is only one French species. It was apparently a species that preferred slow-moving water. Crayford is its latest appearance in England, hence it was then probably dying out. It is certainly a southern form. First record, B. B. Woodward, 1890 [**48**].

Lymnaea peregra (Müller). Very common, 2,000+ specimens seen. Usually rather small. Some specimens are inflated, probably denoting a different habitat. A Palaearctic species, known from the Red Crag to the present. Its northern limit is the summer isotherm of 8°C. A very adaptable form, living under very varying conditions. The dwarfing does not imply cold, for at the limit of its range in Iceland and Kolguev Island the examples are fairly large. First record, W. B. Dawkins, 1867 [**12**].

Lymnaea palustris (Müller). Not common, 226 examples seen. A variety figured in *Science Gossip*, N.S., vol. ii, 1895, p. 40 [**52**] in coll. A.S.K. Rather small, the largest specimen being 20 mm. in height. Ilford specimens attain 35 and Admiralty ones 25 mm. A Holarctic species, its northern limit being the summer isotherm of 8°C, and if the Greenland forms are the same (they are certainly very near) its range extends to the isotherm of 4-5°C. Known range the Cromer Forest Bed to Recent. A variable form according to its habitat. The recent examples from the River Danube are much larger than any others. First record, A. Tylor, 1869 [**19**].

Lymnaea truncatula (Müller). Common, 507 specimens seen. A Holarctic species, its northern limit being the summer isotherm of 8°C. It varies greatly in size, adults collected in the spring being always larger than those found in the summer and autumn. Crayford specimens vary, the largest being 10.5 mm. in height, the maximum for recent specimens being 12 mm. Known range Cromer Forest Bed to Recent. It is more often found out of water than in it. First record, A. Tylor, 1869 [**19**].

Lymnaea stagnalis (Linné). Not common, 62 specimens seen, all young. Semper has stated that newly-hatched animals of this species have so little power in the foot that the feeblest current sweeps them away. Hence, one can conclude that the species lived farther up the stream and was unable to colonize the locus where found. A Palaearctic species, its northern limit being the summer isotherm of 10°C, and in the south it extends to Kashmir. Known range Cromer Forest Bed to Recent. It prefers slow-moving water of some depth. First record, W. B. Dawkins, 1867 [**12**].

Planorbis corneus (Linné). Rare, 30 specimens seen. The examples are often large and well developed. Rather a southern form, its northern limit being the summer isotherm of 15°C. It prefers rather deep slow-moving water. Known range Norwich Crag to Recent, but is rarely common. It attains its maximum development in the Danube. First record, J. Morris, 1838 [**1**].

Planorbis albus Müller. Very rare, six examples seen. Its northern limit is the summer isotherm of 8°C. and is recorded from the Pamirs with a summer isotherm of 4°C. Known range, Cromer Forest Bed to Recent. A Palaearctic species with closely allied forms in N. America. It is curious that it is usually rare in the Pleistocene, but is very common in the Holocene and present day. The living *P. albus* is very adaptable as to habitat, occurring everywhere in permanent water. First record, R. W. Cheadle and B. B. Woodward, 1876 [**30**]. This is probably an error, for *P. laevis* Ald. is a common form at Crayford, and in 1876 the two species were often confounded.

Planorbis laevis Alder. Abundant, 1,500 specimens seen. If the records can be trusted this Holarctic species extends in Greenland to the summer isotherm of 4-5°C. and in the Pamirs, 2°C. Dr. E. Wust, however, states that the Central Asiatic form is not *laevis* Alder. Ranging from Cromer Forest Bed to Recent. In the Cromer Forest Bed it is common, as it is in many Pleistocene beds, but it is very rare in the Holocene and at the present day. Dr. A. C. Johansen has identified *P. arcticus* Beck amongst Crayford specimens, but in my opinion they are only *laevis*. The English Pleistocene form has been named *lateralis* Strickland, and the ecology of the Pleistocene form is quite different from that of the Holocene and Recent. In Pleistocene times it is common in river deposits, whilst in the Holocene it only occurs in lacustrine and marsh deposits, and today in lakes, ponds and ditches. First record, B. B. Woodward, 1890 [**48**].

Planorbis crista (Linné). Not common, 92 examples seen. A Palaearctic species, its northern limit being the Shetlands, summer isotherm 12°C. Known range Cromer Forest Bed to Recent, but as a rule not common. The living form is adaptable as to its habitat, but is most abundant in muddy water. First record, B. B. Woodward, 1890 [**48**].

Planorbis planorbis (Linné). Abundant, 1,500+ specimens seen. A Palaearctic species, the summer isotherm of 14°C. being its northern limit, so is rather a southern form. Known range Cromer Forest Bed to Recent. A closely allied form, *P. praecursor* Kennard and B. B. Woodward, occurs in the Red and Norwich Crags. The living *P. planorbis* prefers slow-moving water which may account for its absence or extreme rarity in many Pleistocene deposits. First record, J. Morris, 1838 [**1**], as *P. carinatus* Müll.

Planorbis vortex (Linné). Very rare, three specimens seen. A Palaearctic species attaining its northern limit in Scotland, summer isotherm 13°C. Known range Cromer Forest Bed to Recent. Prefers running water with plenty of plants. Nearly always a rare species in Pleistocene beds. It is probable that the first record for Crayford (J. Morris, 1838) is an error for *P. leucostoma* Millet. This latter species is abundant at Crayford and is not in the Morris list.

Planorbis leucostoma Millet. Abundant, 814 examples seen. A Palaearctic species, its northern limit Iceland, summer isotherm 10°C. Known range Red Crag to Recent. Apparently has a preference for rather stagnant water. First definite record, A. Tylor, 1869 [**19**].

Planorbis vorticulus Troschel. Very rare, one example seen. First record. A European species, its northern limit being the summer isotherm of 14°C. Known range Cromer Forest Bed to Recent, but it is never a common species. In England it has only been found living in drainage ditches and never in streams or rivers, which may account for its extreme rarity in English deposits.

Planorbis contortus (Linné). Very rare, three examples seen. A Palaearctic species, its northern limit being the summer isotherm 10°C. Its preference is for running water. Known range Cromer Forest Bed to Recent. First record, B. B. Woodward, 1890 [**48**].

Segmentina nitida (Müller). Very rare, five examples seen. A European species that just reaches Asia. Rather a southern form, its northern limit being the summer isotherm 14°C. Known range Cromer Forest Bed to Recent. In England, Yorkshire is its northern limit. Apparently a marsh form, hence its rarity at Crayford. First record, B. B. Woodward, 1890 [**48**].

Segmentina complanata (Linné). Very rare, six examples seen. First record A Palaearctic species, its northern limit being Scotland, summer isotherm 13°C. Known range Cromer Forest Bed to Recent. An adaptable form, occurring in both running water, including rivers, and stagnant.

Ancylastrum fluviatile (Müller). Very rare, six examples seen. A European species, its northern limit being Scotland, summer isotherm 13°C. Known range Cromer Forest Bed of West Runton and Little Oakley to Recent. It requires a hard clean surface for attachment, hence its rarity at Crayford, where such a habitat would only be found on the larger bivalves. First record W. B. Dawkins, 1867 [**12**].

Ancyclus lacustris (Linné). Very rare, seven examples seen. A European species, its northern limit being Scotland, summer isotherm 14°C. Known range Cromer Forest Bed to Recent. This, too, requires a hard clean surface for attachment, but it is usually on the leaves of water lilies or other floating vegetation. Its rarity at Crayford would lead one to infer that these were not present. First record, B. B. Woodward, 1890 [**48**].

Psilunio littoralis (Cuvier). Common, 200 examples seen. Figured specimens. Two valves by J. Morris [**1**], now in Geological Museum 53997 (J.M. 215), 3782 (J.M. 213); one valve figured by B. B. Woodward, 1890 [**48**, p. 379, Figs. 1-2] in British Museum (Nat. Hist.). One valve figured by the author, 1895 [**52**, p. 39], in coll. A.S.K. One figured by A.S.K., E. A. Salisbury and B. B. Woodward, 1925 [**92**, Pl. XX., Figs. 8, 9, 11], in coll. A.S.K.

A southern form, recorded living from France, Portugal, Spain, Italy, Greece, Asia Minor, Assyria, Morocco and Algiers. Of these the three first records are certainly correct. I have examples labelled *littoralis* from Italy, Greece, Algiers and Messina, and these specimens differ very much from French examples, but there is not sufficient material available to say whether these differences are sub-specific or specific. *P. rothi* (Bourguignat) from Irak and *P. semirugatus* (Lamarck) from Asia Minor are closely allied. It is recorded from the Pliocene of Germany, Slavonia, Balkan lands and S. Russia, so is apparently a very old form. All the *Unionidae* vary greatly according to their environment, so the probability is that there is a super-species with several geographical races or sub-species.

Psilunio littoralis occurs in the Pleistocene of Germany (*P. Kinkelini* Haas), but is now extinct there. It also occurs in the French Pleistocene, but is extremely rare. It has been recorded from the Forest Bed of W. Runton, but this identification has been challenged. I have seen fragments of a very thick shell there which might be *littoralis*. It is known from the English Pleistocene of Clacton and Lion Point (Jaywick Sands) and Butlin's Camp, midway between the two; from Cropthorne, Grays, Barnwell Abbey, East Road, Barnwell, Grantchester, Woodston, Overton Waterville, Stutton, Magdalen Park, Oxford, Swanscomb, Brentford, and Westminster, showing that it was a widely spread form occurring in the Thames, Ouse and Severn systems, and one would infer from this that it had been an inhabitant of Britain for a very long period. It is the type of the genus *Migranaja* Hannibal 1912, but *Psilunio* Stefanescu 1896 has priority. *Rhombunio* Germain 1911, type *rothi* Bourg, is another generic name that has been used for *littoralis*. The species varies greatly in size and shape according to its environment, for unlike *Anodonta* it is not restricted to a muddy bottom, but can flourish in numbers, but not in size, in fine gravel and sand.

The largest English specimens are from Crayford and the basal bed at Clacton, and in both localities the maximum breadth is 78 mm. Barnwell specimens are 61 mm., Oxford 53 mm., Milton St. Swanscomb 61 mm., Dierden's Pit, Swanscomb, 46 mm.; all these are from sandy gravel. By the kindness of the Abbe H. Breuil I have been able to examine a large series dredged from the River Oise at l'Isle Adam Seine et Oise. Judging from the associated human artefacts they date from Early Bronze Age and possibly older to the present day and range in breadth from 74 mm. to 43 mm. If one judged their ages by the state of preservation the oldest examples are the largest. In any case they do not attain the same size as the Crayford and Clacton examples. Both Locard and Westerlund cite the maximum as 80 mm., so the English examples are only 2 mm. below, denoting the optimum ecological conditions. From its present distribution it is a southern form, yet since it lives in Northern France it can survive moderately cold winters, though recent French examples are much smaller (c. 45 mm.) than Crayford shells. Much more material, however, is required before one can say that this dwarfing is due to temperature and not to the nature of the stream bed. In the cave of Mas d'Azil (Ariege) this species, as well as *Cepaea nemoralis* (Linné), had been used as food by man, but there is no evidence that this was the case at Crayford, though it may well have been, for a hunting community will eat anything that it can get.

Certain it is that early Holocene folk ate the much larger *Unio auricularia* (Spengler) at Mortlake and the rejected shells furnish the only evidence that this species ever lived in England. First record, J. Morris, 1838 [**1**].

Anodonta cygnaea (Linné). Rare, eight examples determined, but the fragility of the specimens is the cause of this low figure. The examples are all well developed and certainly larger than those living in the Thames today. Rather a southern form, the summer isotherm 14°C in Scotland being its northern limit. It is a widely spread Palaearctic form as far east as Kamschatka. Known from the Forest Bed of W. Runton and from many Pleistocene and Holocene deposits. First record, W. B. Dawkins, 1867 [**12**].

Anodonta anatina (Linné). Very rare, two examples identified. First record. Like the preceding its fragility is the cause of this rarity. It is a common European species and certainly ranging in Scotland to the summer isotherm 14°C., but it has until lately been so confused with *A. cygnaea* that many records are unreliable and even today many Continental authorities will not recognise it as a good species, which it undoubtedly is. In England its known range is from the Cromer Forest Bed to Recent. Apparently in England, *anatina* has more preference for rivers than *cygnaea,* the latter preferring backwaters and the former the streams.

Anodonta minima Millet. Very rare, one specimen in the Geological Museum (Lewis Abbott Coll.). First record. Nothing definite can be said as to its range, for the species has only recently been segregated. It occurs in both the Thames and Severn systems, ranging as far north as Yorkshire, but it is probably rather a southern form, though it certainly occurs in France and Germany. It is not known from the Cromer Forest Bed, but occurs in the Pleistocene of Grays and is extremely rare in the Holocene, Penton Hook being the only locality.

Speaking of the anodons, A. E. Boycott states : " Their essential needs are fish on which they can pass their early parasitic phase and incidentally travel about and a firm muddy bottom in which they can imbed themselves. Why they spend so much of their time two-thirds sunk in the mud I do not know : it seems an extravagant precaution against being swept away by any ordinary current. But a bottom suited to such a life is obligatory. They will not live either on a hard strong or gravelly bottom or on one which is covered with a thick layer of soft humus in which they would have to disappear before they found firm ground " [**108a**, pp. 132-3]. Since the anodons were in the position of life at Crayford this shows that the brickearth was consolidated quickly and only the top inch or so was soft.

Sphaerium corneum (Linné). Very common, 1,422 valves. A widely spread Palaearctic species attaining the summer isotherm of 8-10°C. in Norway, Finland and Siberia. Known range Norwich Crag to Recent. A. E. Boycott states : " It is a useful indicator of pretty good molluscan conditions. It does not like dirty water, nor does it live in drying ponds and streams " [**108a**, p. 135]. First record, W. B. Dawkins, 1867 [**12**].

Sphaerium dickinii Clessin. Not common, 182 valves. This species is only known living from four localities in Germany : Ochsenfurt, Aschaffenburg, Frankfurt and Schwanheim, all on the R. Main, whilst Crayford is the only fossil record. Figured by A. S. Kennard in 1895 [**52**, p. 40] as *S. corneum* var. In Coll. A.S.K. In Germany it is a river form and is rare. The reversal of the hinge noted by Clessin as being frequent in recent specimens also occurs at Crayford, as pointed out to me by D. Kimball. Examples of all ages occur and it was clearly a resident species, for it was found in both the Lower Brickearth and the *Corbicula* Bed. Nothing has been published as to its ecology except that it was a river form. No other species has such a puzzling record.

It does not occur in the French Pleistocene, but the northern French rivers were never connected with the Rhine until man dug canals in recent times. It must have existed before the Crayford stage and from then until to the present day, but it has left no trace. It does, however, strongly support the view that the present European molluscan fauna is a direct descendent from the Pleistocene and that there has been no local extermination by glacial periods with subsequent re-introductions. First record, G. F. Dollfus, 1884 [**39**].

Corbicula fluminalis (Müller). Very common, over 1,000 valves seen. Figured by Sir Charles Lyell from Erith in 1863 [**9**, p. 124, f. 17d], by G. F. Dollfus in 1884, four valves from Erith [**39**, p. 51, Pl. 1 and 2, Figs. 10-13] referred to his var. *amnicoides*, a pair by B. B. Woodward in 1890 [**48**, p. 379, Figs. 3-4]. This pair from the Lower Brickearth at Crayford (Spurrell Coll.) are the largest English examples known, measuring ht. 33 mm., br. 37 mm. and 18 mm. thick. They are in the British Museum (Nat. Hist.), and are only excelled in size by specimens from the dry bed of the Amur Daria in Central Asia (37 x 42 mm.) and from Lake Waler in Kashmir (35 x 40 mm.). Examples occur of all ages from the smallest fry ; the valves are often united and in the Lower Brickearth are in the position of life. These facts show that the environment was very favourable for the species.

Corbicula fluminalis is the best known of the Pleistocene mollusca, the literature relating to it is enormous and the opinions respecting it differ greatly. The genus does not live in Europe today and its present range is decidedly southern. Nothing is known as to its life history, but we do know that the genus prefers mud, but can live in sand or sandy gravel. Species vary greatly according to their habitat and specific differences are not well marked. I have failed to detect any valid specific differences between the English fossil examples and those now living in the Euphrates and the Nile. Hence the well-known trivial name of *fluminalis* (Müller) is used. This name is based on specimens from the Euphrates. Over 100 different names have been applied to what I should call *fluminalis*. It now lives in Asia Minor, Transcaucasus, Persia, Palestine, Mesopotamia, Turkestan, Kashmir and North Africa. In comparatively recent times it was abundant in many parts of North Africa, where it is now extinct owing to desiccation. It is always very abundant where it does occur. In England it first appears in the Norwich Crag and, considering the very small amount of excavating that has been done, it is common. Nyst in 1838 described his *duchastelii* from Norwich Crag examples. It is rare in the succeeding Weybourne Crag and Forest Bed of West Runton, but is absent from Little Oakley and from the older part of the High Terrace at Swanscomb ; it is common in the later beds at Swanscomb and in the succeeding stages of the Thames at Grays and Ilford, Crayford being the latest deposit in which it occurs. Elsewhere in England it is common in the Pleistocene, especially in the Cambridge Gravels and at Stutton, where the examples are nearly as large as at Crayford ; *trigonula* S. V. Wood, 1834, was based on Stutton specimens. It was common at West Wittering, but the examples are small and the species apparently did not like peaty deposits.

In the Severn river system *fluminalis* is very rare, the only record being Ailscott, but the Pleistocene beds of Othery, Sedgemoor, where it occurs, may have been part of that river system. As a derivative it is found in the March Gravels, at Kelsea Hill, Paull and Burstwick, Yorks, and Croxton, Lincs. In France it is very rare, being only known from the older Pliocene of Bligny, Menchecourt (three valves found by Prestwich) and at Cergy, where over 1,000 valves were obtained by Laville. In Germany it has been recorded from a few localities. Elsewhere it has been recorded from Greece, Sicily (*gemmellaeii* Philippi, 1836), Siberia, Denmark, Holland, Belgium and North Africa—a puzzling distribution. Why it should be rare in France and Germany and so common in England is a mystery, and yet in England it is sporadic, for there are many Pleistocene deposits (e.g., Westminster) where it is absent, yet the conditions were apparently suitable.

Attempts have been made to base conclusions on the proportion of height to width [**104**], but this is not constant in any locality, except in brickearths where the height is always less than the breadth. I examined two series from Grays, one of my own collecting, and another in the Geological Museum made many years before from a different locus, and the series differed. In the older one in more than half the specimens the height was greater than the width, whilst in the other series the majority had the same width and height, the remainder being equally divided between the other two variants. It is the custom to call the high form, often with a thickened umbo, var. *cor* (Lamarck), but it is the type of Müller's species. G. F. Dollfus, in 1884, figured a number of specimens from the Pleistocene of Ostend and described and figured four varieties [**39**]. This shows clearly the great variation in the species in one locality.

One can safely deduce from the abundance and development of this species that the environment was favourable at Crayford and that the winters were warmer than today. They were clearly very prolific and there was a heavy mortality amongst the young, though since the valves are perfect, fish were apparently not their enemies. When the life history of this species is known more deductions can be made. As it is, one can safely say that the Lower Brickearth was deposited under warmer conditions than today. First record, J. Morris, 1838 [**1**].

Pisidium amnicum (Müller). Very abundant, over 3,600 valves. Figured specimens : T. D. A. Cockerell figured and described a valve of this species with a mended fracture in 1890 [**45**, pp. 4-5]. This feature was discussed by me in 1895 [**52**, pp. 39-40]. B. B. Woodward figured a pair in 1890, measuring 9 x 11 mm. [**48**, p. 379, f. 6] ; B. B. Woodward in his Monograph of the Pisidia, 1913 [**78**] figured a number of examples (Pl. V., Figs. 4, 5, 7, Pl. VII., Figs. 2, 3, 4, Pl. IX., Figs. 1, 3, 4, 5, 6, 7). He states : " The only pearl I have seen in a *Pisidium* is in a specimen from Crayford," Pl. IX., f. 7c [**78**, p. 19]. All B. B. Woodward's figured specimens are in the British Museum (Nat. Hist.).

Rather a southern form, but its northern limit is Finland, summer isotherm 10-12°C. A Holarctic species, but in Siberia not known east of L. Baikal. It is restricted to clean-running water in rivers, streams, canals and lowland lakes [**108a**, pp. 135 and 138]. Geologically its known range is Norwich Crag to Recent, and is one of the commonest fossils in the Pleistocene.

Its original home was probably S.E. Europe. It is very variable at Crayford, but nearly all the specimens have been obtained from the *Corbicula* Bed. This is a river deposit and represents the sweepings from various different loci. Most of them are of the normal stream form, but some are decidedly trigonal, though this is not so marked as at Grays. First record, J. Morris, 1838 [**1**].

Pisidium sulcatum S. V. Wood. Common. This is usually called *astartoides* Sandberger, but German authorities have lately been using *clessini* Neumayr. The synonymy is as follows :

1840. *Cyclas* (*Psidium*) *amnica*, var ? : Lyell, Lond. and Edinb. Phil. Mag., Ser. III, XVI, pp. 363 and 364, Figs. ; id. Antiq. Man., p. 217, Figs., p. 218, from West Runton.

1851. *Pisidium amnicum*, var. *sulcatum* : S. V. Wood, Crag Moll. (Pal. Soc. Monog.), II, p. 110, Pl. XI, f. 1b, from Grays.

1864. *Pisidium antiquum*, n. sp. Martens, Zeitschr. Deutsch. Geol. Gesell., XVI, p. 349 (non Braun, 1851), from Irtisch bei Omsk. Siberia.

1875. *Pisidium clessini* : Neumayr, in Neumayr and Paul, Anhandl. der K.K. geolog. *Reichsanst.*, VII, 3, p. 25, Taf. XII, Fig. 30 a-d from the Levantine *stricturata* zone of Middle Paludina beds of Ciglenik (Slavonia).

1880. *Pisidium astartoides* : Sandberger, *Palaeontographica*, XXVII (N.F. VII), p. 96, Pl. XII, f. 1-1e, from West Runton.

1883. *Pisidium charpyi* : Locard, Ann. Acad. Macon (2), VI, p. 126, Tab. IV, Figs. 7-9.

1893. *Psidium clessini* Delafond et Deperet Les Terrains Tertiaries de la Bresse, etc., p. 134, Tab. VIII, Figs. 58-60, p. 156, Tab. IX, Figs. 10-12, from the Middle Plaisancian of Cormoz (Ain) and Upper Plaisancian of Bligny-sous-Beaune, Auvillars and Broin (Cote d'Or).

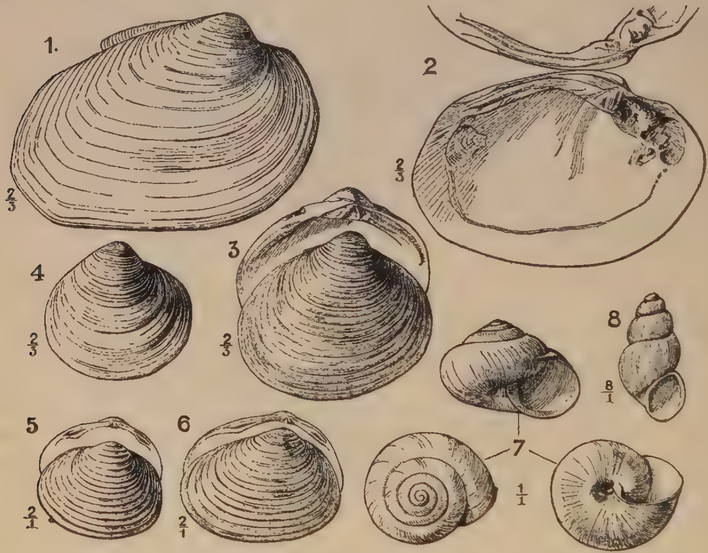

Fig. 18.

1 and 2.—*Psilunio littoralis* (Cuvier) Erith.
3 and 4.—*Corbicula fluminalis* (Müller), Crayford.
5.—*Pisidium sulcatum* S. V. Wood, Crayford.
6.—*Pisidium amnicum* (Müller), Crayford.
7.—*Fruticicola fruticum* (Müller), Ilford.
8.—*Belgrandia marginata* (Michaud), N.E. London.

1913. *Pisidium astartoides* Woodward. Catalogue Brit. Species of Pisidium, p. 27, Pl. 1, Fig. 2, Pl. III, Fig. 2, Pl. V, Fig. 10, Plates 10-12.

1926. *Pisidium astartoides* Kennard and Woodward, Synonymy of Brit. Non-marine Mollusca, p. 311.

1927. *Pisidium astartoides* Geyer Unsere Land—und Susswasser—Moll. 3rd Edit., p. 194, Taf. XXIX, Fig. 5.

1929. *Pisidium clessini* Wenz Archiv. Moll., Vol. VIII, pp. 185-9.

The valve figured by S. V. Wood is certainly this species and is the type. It is probably in the Norwich Museum. That contemporary workers confounded it with strongly sulcate examples of *P. amnicum*, has no bearing on the matter. The name was apparently a MS. name of G. B. Sowerby [**11**]. See Fig. 18.

Figured specimens :

B. B. Woodward, 1890, as *astartoides* Sandb. [**48**, p. 379, f. 5].

B. B. Woodward, 1913, as *astartoides* Sandb. [**78**, Pl. X, f. 1, Pl. XII, f. 4]. These three specimens are in the British Museum (Nat. Hist.). In England it occurs in the Norwich Crag of Bramerton, is abundant in the Forest Bed of Norfolk, Suffolk and Little Oakley, absent from the older beds of Swanscomb though common in the later, and is also known from Clacton, Lion Point, Grays, Ilford, Clapton, Hackney, Othery Sedgemoor, Somerset and Shipton-under-Wychwood, Oxon. Though known from the French Pliocene, it has not been found in the French Pleistocene. It is known from the Pleistocene of Denmark, from four localities in Germany, including Mauer and Mosbach, from the Upper Pliocene of Val d'Arno, Italy, and from the Levantine of Rumania. Being extinct, its ecology can only be inferred from the deposits in which it occurs, but it is probably a river or stream form, and from its frequent association with *Corbicula fluminalis* it may be assumed that it is a southern form. First record, B. B. Woodward, 1890 [**48**], as *astartoides* Sandb.

Pisidium cinereum Alder. Common. Figured specimen B. B. Woodward, 1913, as *casertanum* (Poli) [**78**, Pl. XVII, Figs. 1, 2] in British Museum (Nat. Hist.). An ubiquitous species with a circumpolar distribution, occurring in Lake Biva in Japan. Its northern limit is Iceland, summer isotherm 8°C. Known range, Norwich Crag to Recent. First record, B. B. Woodward, 1913 [**78**].

Pisidium nitidum Jenyns. Very rare, 3 valves. Widely spread over Europe, its northern limit being Iceland, summer isotherm 8°C. Known range, Cromer Forest Bed to Recent, but usually rare in a fossil state. Apparently prefers clear water. First record, A. S. Kennard and B. B. Woodward, 1901 [**60**].

Pisidium milium Held. Very rare, 4 valves. A Palaearctic species ranging from Iceland to N. Italy and the Balkans, its northern limit being the summer isotherm of 8°C. Its range in time and ecology are identical with those of the two preceding species. First record, B. B. Woodward, 1913 [**78**].

Pisidium sultruncatum Malm. Common. A Palaearctic species ranging as far east as Lake Baikal. Also occurs in N. Africa. Its northern limit is Norway, summer isotherm 14°C. ; prefers running water. In a fossil state it is known from the Cromer Forest Bed onwards and is common in many Pleistocene beds. First record, B. B. Woodward, 1913 [**78**].

Pisidium henslowanum (Shepp). Abundant. Figured specimens : B. B. Woodward, 1913 [**78**], Pl. XXII, Figs. 26-29. Fig. 29 S and T show a mended fracture, Pl. XXIV, Figs. 8-9. All in British Museum (Nat.Hist.). A Palaearctic species, known living from Norway to Sicily, and east to Siberia, its northern limit being the summer isotherm 14°C. It has a decided preference for running water. Known from the Coralline Crag of Sutton, it is common in the Cromer Forest Bed and many Pleistocene and Holocene deposits. First record, G. F. Dollfus, 1884 [**39**].

Pisidium lilljeborgi Clessin, rare 20 valves. Figured specimens B. B. Woodward, 1913, 78, Pl. XXVIII, Figs. 21 and 26. In British Museum (Nat. Hist.). A Palaearctic and probably a Holarctic species, ranging certainly from Iceland and Lapland to Switzerland, occurs in Lake Baikal and probably in Kashmir and N. America. Its northern limit is Iceland, summer isotherm 8°C. " It lives in clean gritty sand or silt, not mud, in mountain lakes both at high altitudes and near sea level, in both hard and soft water and the determining factor seems to be the nature of the bottom rather than of the water " [**108a**, p. 136]. In England it is not known living south of Lancashire and Yorkshire. It is known from the Cromer Forest Bed and from a number of Pleistocene deposits including Ilford as well as from the Holocene, being common in some Irish *chara* marls. This shows that climate is not a determining factor in its distribution, for the *chara* marls were certainly deposited under warmer conditions than now. First record, B. B. Woodward, 1913 [**78**].

Pisidium supinum A. Schmidt. Rare, 10 valves. Figured specimens, B. B. Woodward, 1913, 78, Pl. XXV, Fig. 7, Fig. 9G to N (9 A-F though said to be *supinum* are *moitessierianum* Palad), Pl. XXVI, f. 4 (Fig. 3 is also this species and not *supinum*), all in British Museum (Nat. Hist.). A Palaearctic species ranging as far east as Lake Baikal. *Supinum* lives in mud in rivers, usually large ones [**108a**, p. 36]. It is unknown living in Wales, Scotland or Ireland ; known from the Norwich Crag and is common in the Cromer Forest Bed at West Runton and Little Oakley, as well as in many Pleistocene and Holocene deposits. Rather a southern form, its northern limit being Denmark, summer isotherm 15°C. First record, A. S. Kennard and B. B. Woodward, 1905 [**68**].

Pisidium moitessierianum Palad. Common. Figured specimens B. B. Woodward, 1913, 78, Pl. XXV, Figs. 9 a-f, miscalled *supinum*, Pl. XXVI, Fig. 3, also miscalled *supinum*, all in British Museum (Nat. Hist.). A Palaearctic species ranging throughout Europe to Lake Baikal and south to Switzerland. Its northern limit is the summer isotherm 14°C. " Lives in mud in rivers, is very small and liable to be overlooked " [**108a**, p. 36]. Common in the Forest Bed at West Runton and Little Oakley, and also in many Pleistocene and Holocene Beds. First record, A. W. Stelfox, 1918 [**86**].

It is only within the last twenty-five years that the criteria for separating the smaller species of *Pisidia* have been known, and many of the older records are quite unreliable. The probability is that when they have received more attention their distribution in time and space will be greater than that now given. It will be noted that the most abundant forms at Crayford are stream forms. This may arise from the fact that practically all the specimens were from the *Corbicula* Bed which is a definite stream deposit.

Pupilla muscorum (Linné). The most abundant land mollusc, over 600 specimens. A Holarctic species, its northern limit being Iceland, summer isotherm 8°C. From its distribution it is an ancient species and it is known from the Red Crag of Butley, the Norwich Crag of Bramerton and Yarn Hill and from the Weybourne Crag of North Walsham. It is rare in the Forest Bed of W. Runton and Little Oakley and also rare in all the early Pleistocene beds, whilst in the later Pleistocene it is often abundant and is not uncommon in many Holocene deposits. An adaptable species, being common on dry grass-land and sometimes in marshes, but on the former it is usually small. The Crayford examples are well developed, but the species is of little use as an indicator of conditions. First record, J. Morris, 1838 [**1**].

Vallonia pulchella (Müll.). This name as used by older authors covered an aggregate of three species, *pulchella* (Müll.), *excentrica* Sterki and *costata* (Müll.). All three occur at Crayford. I have seen nine examples of the first, 42 of the second and six of the third. They are all Holarctic, very adaptable and probably date back to the Pliocene, whilst their ecologies are apparently very similar ; at the roots of grass being a favourite habitat. From the preponderance of *excentrica*, one would infer that the grassland was rather dry.

Zua lubrica (Müll.). Very rare, one example. A Holarctic species with its northern limit in Iceland, summer isotherm 8°C. Known from the Red Crag of Butley, it occurs in the Forest Bed of West Runton and Little Oakley and is known from many Pleistocene and Holocene beds. At the present day it is very adaptable and is widely spread and common, as it was apparently in the Holocene. In the Pleistocene it is sometimes very abundant, as at Barnwell, but in other places very rare, as at Dierden's Pit, Swanscomb. One would infer an inhibiting factor which was not always present to account for these differences. First record, B. B. Woodward, 1890 [**48**].

Limax sp. Fairly common. One can infer that the banks of the stream were not very dry. In the Cromer Forest Bed the internal shells of slugs are abundant, but they are much rarer in Pleistocene beds. The internal degenerate shells of the slugs, as a rule, cannot be determined specifically or even generically. It is quite possible that under *Limax* sp., I have included *Agriolimax* sp. and *Amalia* sp. There are no large shells that could be either *maximus* Linné or *cinereoniger* Wolf, nor are there any of the small shells that might be *laevis* Müll, but this species is now said, though not proved, to be an aggregate. They are all of middle size and it is possible that some may be *L. arborum* Bouch-Chant. Slug " species," being based mainly on anatomy, have apparently a lower status than those of mollusca, whose shell is well developed.

Candidula radigueli (Bourguignat). Not common, over 40 specimens seen. This is the species that has been known as *caperata* (Mont), *candidula* (Studer) and *crayfordensis* Ken. and B.B.W. It is only known with certainty from the Pleistocene of England and France. In England it occurs at Trumpington, Barnwell and Grantchester, (Cambs.), Woodston, (Northants), Brentford and Westminster, (Middlesex), Clacton and Ilford, (Essex), Swanscomb, Crayford and Folkestone, (Kent). It was most abundant at Ilford (Uphall Pit), where it was the commonest helicoid. In France it occurred at Clichy and Joinville le Pont 30m. Terrace, the 10m. Terrace of Rethondes (Oise) and the tufa of La Celle. (Seine-et-Marne). In this last locality the associated flora was markedly southern. It may have been found at Abbeville (40m. Terrace), St. Acheul 30m. Terrace and Menchecourt 10m. Terrace ; judging from the records of *Xerophila* from these three deposits, Fagot's record from Villefranche, Pyrenees, needs confirmation. It is not recorded, and I have not seen it from Germany, but it is possible that it has been confounded with *Helicopsis striata* (Müll.). This is certainly a southern form judging from its allies. First record, W. B. Dawkins, 1867 [**12**] as *Helix caperata* Mont.

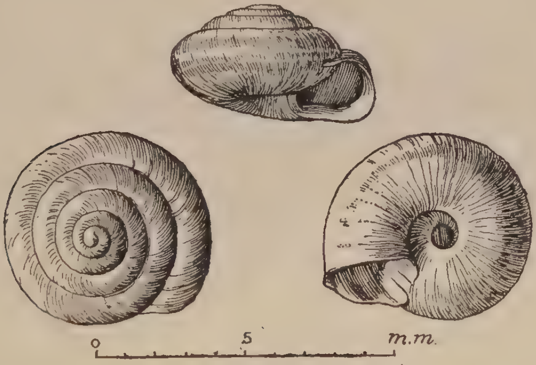

FIG. 19.

Candidula radigueli (Bourguignat)=Crayfordensis. (Kennard and Woodward) Pleistocene Ilford. *Proc. Malac. Soc. Lond.*, xi, 1915, p. 270.

Trochulus hispidus (Linné). Not common, 60 examples. A Palaearctic species ranging as far north as the Faroes, summer isotherm 11°C. As a fossil, it is known in the Red Crag of Butley from several localities in the Norwich and Weybourne Crag in the Cromer Forest Bed and in most Pleistocene and Holocene deposits. The form occurring at Crayford is large and flat, very similar to the one so common in the High Terrace at Swanscomb and still living in the marsh meadows of the Thames. The Pliocene examples are rather small and decidedly high spired, and the flat form does not appear till the Cromer Forest Bed. An ubiquitous species thriving in both dry and damp loci, but require shelter in the former. Under arid conditions, as on the Chalk downs, this species is always small (var. *nana* Jeff.), but small forms occur in damp meadows, so it is probable that there are fixed " races," irrespective of humidity, as in *Arianta arbustorum* (Linné). First record, J. Morris, 1838 [**1**].

Cepaea nemoralis (Linné). Rare. Two perfect examples from the Lower Brickearth and six apices from the *Corbicula* Bed. Both the perfect examples are very large, the larger one being 29 mm. on diameter and 21 mm. high, and as B. B. Woodward states : " Rivals the biggest specimens from southern Europe " [**48,** p. 378]. A European species with a decided southern distribution, its northern limit being Norway, summer isotherm 14°C. and eastward to west and south Russia. It is known from the Red Crag of Butley, from the Cromer Forest Bed and from many Pleistocene and Holocene beds.

This is one of the few species that we can say varies in size according to the latitude, the southern forms being the larger. J. W. Taylor in his Monograph gives the diameter as 20 mm. I think this is an understatement even for Yorkshire, where he lived. Kentish specimens are 22-23 mm., as a rule, though some colonies on the Chalk hills are 24 mm. ; Millport, Scotland, are 22 mm. in size ; Largo, Fife, 21 ; Caldey, Pembroke, 23 mm. ; Steep Holm, Bristol Channel, 25 mm., whilst on Aran Island and at a few other localities in W. Ireland 27 mm. For the Continent, one can cite Abbeville 24 mm., Moirans Isere 27 mm., Geneva 27 mm., Bordeaux 28 mm., Pyrenees 33 mm. (var. *gallica* West), Tuscany 31 mm. (var. *lucifuga* Hart.).

English Pleistocene forms are decidedly larger than the Recent. The following are some of the figures, Woodston 22 mm., Barnwell 23, Clacton, Ilford, Ightman 24, Caldey 26 and Swanscomb 27. This is also true for Continental examples. A. Locard, when describing the large form as a new species *depereti* from La Baume d'Hostun, Drome, gives the diameter as 30-32 mm. and notes that the largest recent example of *nemoralis* from the locality was 25 mm. and from the Rhone Valley 28 mm. *Williamsiana* Nevill, another synonym, from the Pleistocene of Nice, is described as 30.5 mm., recent examples attain only 27 mm. *Tonnensis* (Sandb.) from the Pleistocene of Burgtonna Thuringia, is 32 mm., whilst recent S. German examples are 25 mm. From the above facts one can infer that during the deposition of the Lower Brickearth the summers were much warmer than they are today and approximated to those of Southern France. First record, W. B. Dawkins, 1867 [**12**].

Ceciliodes acicula (Linné). Very rare, four specimens. This subterranean species can penetrate to a great depth, for I found a living specimen in the Lower Loam of Milton St. Pit, Swanscomb, at a depth of 18 ft. from the surface. It had reached this depth by travelling down the hole left by a decayed root. The Crayford specimens came from the *Corbicula* Bed and are all waterworn and by every test are certainly contemporary with the deposit. It lives in dry places from Portugal to Asia Minor and the Caucasus, but is absent from Russia. Its northern limit is in England and Norway, summer isotherm 16°C. and is certainly a southern species. In England it appears first in the Pleistocene, where it is always very rare, but becomes common in the Holocene, especially in chalk hillwashes. First record, A. S. Kennard and B. B. Woodward, 1901 [**60**].

Succinea pfeifferi Rossmässler. Not common, 34 examples seen. A Palaearctic species, its northern limit being N. Iceland, summer isotherm 8°C. Known from the Red Crag of Butley ; it is common in the Forest Bed of Norfolk. It is common in those Pleistocene beds, where the ecology is favourable and in similar Holocene deposits. It is essentially a swamp form, and in those conditions it is abundant. Its rarity at Crayford shows that there were no adjacent marshes and very little aquatic vegetation. First record, R. W. Cheadle and B. B. Woodward, 1876 [**30**].

Succinea oblonga Draparnaud. Very rare, only one example seen, and that is not typical and the record must be considered doubtful. Said to be a Palaearctic species attaining in Siberia to its northern limit summer isotherm of 10-12°C. Its recorded presence in the Norwich Crag and Cromer Forest Bed is very doubtful, but it was certainly abundant in the Pleistocene of Barrington, associated with *Hippopotamus* and in a number of late Pleistocene deposits. *Succinea* is a genus where the shell is clearly degenerate and the identification of species by the shell alone is almost impossible. On excellent anatomical grounds *S. oblonga* Auct. is now known to be an aggregate of two species, *S. oblonga* vera and *S. arenaria* Bouch-Chant. Both species live in England and occur sporadically in a few isolated localities, though abundant where they do occur. It is extremely difficult to separate them by the shell in a recent state and still more so when fossil. They have different habitats, *arenaria* living on sand dunes and *oblonga* on marshes subject to flooding. Thus, no conclusions can be drawn from its presumed presence at Crayford. First record, R. W. Cheadle and B. B. Woodward, 1876 [**30**].

(f.) Conclusions drawn from Freshwater Mollusca.

I have already given the inferences to be drawn from the presence, development and relative abundance of the various species and they may be summarised as follows :

1. The Lower Brickearth was deposited by a slow-moving stream with but little aquatic vegetation. The summer temperature was higher than that of today and the winter certainly not colder, but probably warmer.

2. The *Corbicula* Bed was deposited by a quick-flowing stream with a sandy bed and an absence of pebbles. Had there been many stones, *Ancylastrum fluvatile* would have been abundant, as in the Thames of today and the old Thames of the High Terrace. The climatic conditions were the same as those of the Lower Brickearth, at least there is no evidence of any change.

(g.) Conclusions drawn from Land Mollusca.

Compared with other Pleistocene deposits land mollusca are comparatively scarce in the Crayford Brickearth and one would infer that there was but little flooding of the adjacent ground, for that is the principal cause of their presence. There is a total absence of woodland forms, which are so common in the High Terrace of Swanscomb, and a marked scarcity of semi-aquatic species. The former shows that the country was open grass-land, the latter that there were no marshes and but little aquatic vegetation, this conclusion being supported by the evidence from the fresh-water forms. As to the climate, it was clearly warmer than it is today. Though *Candidula radigueli* is an extinct species, all the species of the genus are Mediterranean today and their diffusion to the north is due to human agency in the last thousand years. The inference to be drawn from the large size of *Cepaea nemoralis* has already been noted. The summers may well have been as warm as those of the South of France and the winters were probably milder than those of Kent of today.

At Crayford one sees the last appearance in the English Pleistocene of *Corbicula*, *Psilunio*, *Paladilhia*, *Candidula radigueli* and *Pisidium sulcatum*. Of these the first and last were survivors from the Pliocene. Other early Pleistocene species such as *Theodoxus cantianus*, *Belgrandia marginata*, *Viviparus diluvianus*, *Lymnium cantianus* and *Sphaerium solidum* had apparently all disappeared before the Crayford stage. The one newcomer is *Sphaerium dickinii*. Nearly all the others are known from the Forest Bed and there is no reason apart from theory why they should not have lived here without any break since Forest Bed times.

As already noted, I have examined a large quantity of material from Northern France and it is interesting to compare the French faunules with the English. The land mollusca are practically identical with the exception of two or three species which are rare in the French Pleistocene and unknown in the English. One can thus postulate a land-bridge probably where the Straits of Dover now exist. But such a bridge would be a barrier to the freshwater forms and we find marked differences. There is a total absence in the French beds of any species of *Viviparus* or *Theodoxus*, *Valvata antiqua*, *V. naticina*, *Bithynia inflata*, *Lymnium cantianus*, *L. pictorum*, *L. tumidus* and *Pisidium sulcatum*. These all occur in the English Pleistocene and in Germany, though their true home is probably S.E. Europe. This situation is best explained by the view that in early Pleistocene times the Thames and Rhine were connected, but the Northern French rivers were never part of the Thames-Rhine system. The break between the Rhine and the Thames probably occurred at the end of the Clacton episode, for the latest bed there is marine, showing that the sea had made a big inroad on the " North Sea plain." The French rivers drained into the Channel, which was probably of greater extent on the English side judging from the marine deposits in Sussex.

If one compares the molluscan faunules of the Forest Bed, the High Terrace of the Thames, Grays, Ilford, Westminster and Crayford, it is clear that they form one series and that there is no marked break as there would have been if there had been an intervening glacial period with the wholesale destruction of life that it would entail. Each stage is linked on to the preceding and succeeding ones. Many species occur in all and are still with us, whilst others appear and disappear. Snails unlike the larger mammals cannot migrate, and had there been a glacial period it would have been just killed off and the re-population would have taken thousands of years and the period of time required if the multiple glacial theory is adopted would be enormous. The geological world is divided into two camps ; the glacialists who postulate ice ages as though they were local phenomena and not world-wide in their influence as they would be, and the palaeontologists and palaeobotanists who say that something abnormal happened at the end of the Pleistocene ; but whatever it was, whether ice or water, the then existing invertebrata and plants were not exterminated, but that the vast majority survived to the succeeding Holocene.

Palaeontology always has the last word.

VII. SUMMARY OF CONCLUSIONS.

Having already moted the deductions to be made from the various lines of evidence, a summary is all that is needed.

The Crayford Series contains three well-marked beds, probably widely separated in time.

1. The Crayford Gravel, exposed notably at Slades Green.
2. The Lower Brickearth, including the *Corbicula* Bed.
3. The Upper Brickearth and Trail.

1. The Crayford Gravel. This bed indicates a quick-flowing river. There is not sufficient evidence to fix the climate, but it was probably warm. In age it is posterior to the cutting of the bench and probably represents the close of that episode. There was a great interval of time between beds 1 and 2. During this period there was a marked uplift of the land and a lower bench was eroded at 20 ft. O.D. Hence the top of bed 1 became a land-surface, on which

Homo, using Levallois technique, lived. There is no clue as to when this occupation took place, but it was probably towards the end of the interval. Elsewhere, as at Westminster, deposits resting on the —20 ft. O.D. bench have yielded many remains of *Elephas antiquus* and *Dama clactoniana*, showing that the old fauna of the High Terrace was still surviving and that these beds are older than the lower brickearth of Crayford, though resting on a lower and newer bench. Then followed a change in the relative levels of the land and sea and a period of aggradation ensued culminating in the deposition of the Lower Brickearth to a height of 30 ft. O.D.

2. Lower Brickearth. This is the product of a sluggish stream, not very deep, six feet at the most, and probably less, with but little aquatic vegetation. The bottom was not very muddy, but fairly hard. *Homo* was living on the banks and his food debris was incorporated in the deposit as the water rose to higher levels and his squatting sites were covered. The same race inhabited the area both before and during the deposition of the bed. From the vertebrate and invertebrate evidence the summers were much warmer than those of today and the winters milder. The overlying *Corbicula* Bed shows that a reverse movement had set in and that the river was again running strongly, but the climatic conditions were the same. A greater rainfall than that of today is suggested to account for the extent and volume of the beds.

3. Upper Brickearth including the trail. This is not a river nor an aeolian deposit, but is the result of sludging from higher ground during a period of greatly increased rainfall. There was at least one interval during the deposition, when a land surface was established with a small pool containing mollusca and plants, but this was followed by more sludging. The three species of mammals throw but little light on its age, for they have a fairly wide range on time. Negative evidence, too often arises from lack of collecting, but the absence of Reindeer, the characteristic late Pleistocene form, should be noted. On the Crayford evidence one can only say that it was certainly not very cold. As to the relative position of the Crayford Brickearths in the Pleistocene sequence of the Lower Thames Valley, it is clear from all the evidence that the position assigned to it by M. A. C. Hinton in 1926 is correct [**93**, pp. 126-136]. With the aid of recent field work the sequence may be stated as follows :

1. High Terrace (Swanscomb) deposits, comprising three well-marked horizons:—
    - a. Basal Gravel and Lower Loam.
    - b. Lower Middle Gravel.
    - c. Upper Middle Gravels (Marston's channel, shelly gravels in Dierden's and Rickson's pits).
2. Grays Thurrock deposits (the old sections).
3. Ilford (Uphall pit) Brickearths.
4. Ilford (Cauliflower pit) Brickearths.
5. Crayford Lower Brickearth and *Corbicula* Bed.
6. Crayford Upper Brickearth.
7. Ponders End deposits.

There are other stages such as Westminster, which are not represented in the Lower Thames so far as we know, and all one can say of the Crayford Gravel is that it is probably between 4 and 5.

An attempt has been made to collect all the evidence and to make deductions from that alone, without reference to any theories. Whether this has been accomplished must be left to others to judge, but one thing is clear, the last word has not yet been said on the Crayford Brickearths. It must always be a matter of deep regret that F. C. J. Spurrell did not publish more on the subject. His papers are very terse and too often he only states his conclusions, usually correct. He omits the evidence on which they are based, but he was very reluctant to publish and only did so under pressure, whilst he could never be persuaded to finish his paper on the High Terrace.

VIII. ANNOTATED BIBLIOGRAPHY.

1. 1838. Morris, J. "On the deposits containing Carnivora and other Mammalia in the Valley of the Thames." *Ann. Mag. Nat. Hist.* Series II, vol. ii, pp. 539-48. The last two pages contain G. B. Sowerby's descriptions and figures of the new shells. An excellent account of the deposits, with four sections and lists of mammalia and mollusca. Though said to be at Erith one section is clearly that at Stoneham's pit, Crayford, but Erith was then better known than Crayford.
2. 1843. Morris, J. "A Catalogue of British Fossils." It is curious that though Morris listed ten species of mollusca in 1838 only three are recorded here.
3. 1844. Owen, R. "A History of British Fossil Mammals and Birds." *Arvicola amphibia* (Linné) recorded in error from Erith and Crayford (p. 205).
4. 1845-9. Falconer, H. and Cautley, Sir P. T. "Fauna antiqua Sivalensis." For a corrected explanation of the Plates see 15, vol. ii. Molar of *Elephas antiquus* from Slades Green figured.
5. 1851. Wood, S. V. "Crag Mollusca Bivalves." pp. 109-10, Pl. XI, f.1.B. *Pisidium amnicum* (Müll) var. *sulcatum* from Grays described and figured.
6. 1856. Wood, S. V. "Crag Mollusca," vol. ii, appendix pp. 304-10. Mentions Erith but not Crayford. The author had apparently no personal knowledge of these brickearths and their mollusca. Morris' records (1) are omitted.
7. 1858. Morris, J. Excursion of Greenwich, Nat. Hist. Club to Bexley and Crayford. ? Privately printed ; apparently not in Brit. Mus. (Nat. Hist.) Library. Copy in Bib. A.S.K. The party visited the Grantham and Spurrell collections and the pits. Records *Elephas antiquus*, *E. primigenius*, *Rhinoceros leptorhinus* and *Cervus* (*Strongyloceros* ?) apparently on the authority of Falconer, who had inspected the Grantham Coll. just previously and probably the Spurrell Coll., though this is not stated.
8. 1858. Jardine, Sir W. "Memoirs of Strickland." *Unio antiquior* Strickland MS. from Cropthorne described pp. 96-7, figured p. CLVIII= *Psilunio littoralis* (Cuvier).
9. 1863. Lyell, Sir Charles. "The Antiquity of Man." *Cyrena fluminalis* (Müll) figured from Erith p. 124, f. 17d. 1873. 4th Edition, p. 170.
10. 1866. Dawkins, W. B. and Sandford, S.A. "Monog. Brit. Pleist. Mamm.," vol. i. List of specimens of *Felis spelaea* Goldf. from Erith and Crayford (p. 152). Four figured.
11. 1866. Wood, S. V., Junr. "On the structure of the Thames Valley and its contained deposits." *Geol. Mag.*, vol. iii, pp. 57-63, 99-107. Theoretical.
12. 1867 Dawkins, W. B. "On the age of the Lower Brickearths of the Thames Valley." *Quart. Journ. Geol. Soc.*, vol. xxiii, pp. 91-109. Sections and lists of mammalia and mollusca. First records of *Canis lupus* Linné, *Ursus arctos* Linné, *U. spelaeus* Rosen, *Rhinoceros antiquitatis* Blum, (as *R. tichorhinus* Cuvier) *R. hemitaechus* Falc. (as *R. leptorhinus* Owen).
13. 1867. Dawkins, W. B. "On the dentition of *Rhinoceros leptorhinus* Owen," *Quart. Journ. Geol. Soc.*, vol. xxiii, pp. 213-227. Recorded from Crayford in Grantham and Spurrell Colls. This record and some of those in 12 were taken from the unpublished M.S. of Falconer, who had seen these collections on September 30th, 1863 (see 15, p. 398).
14. 1867. Dawkins, W. B. "Age of the Thames Valley Deposits," *Geol. Mag.*, vol. iv, pp. 564-5, reference to the Railway Cutting West of Dartford. Dawkins in all his papers laid great stress on the presence of *Rhinoceros megarhinus* Christ, but Falconer always thought that a mistake as to locality had been made.
15. 1868. Falconer, H. "Palaeontological Memoirs," 2 vols. Several figures of and many references to Crayford specimens. Falconer's early death was a great blow to Palaeontology. Had he lived to finish his work his master mind would have ended many errors. As it is we have only his rough notes to show how great a loss his death was.
16. 1868. Wood, S. V., Junr. "Reply to Mr. Dawkins on the Thames Valley Deposits, etc.," *Geol. Mag.*, vol. v, pp. 42-44. Refers to the Brickearth in the Railway Cutting (Dartford Loop).
17. 1868. ——— *Geol. Mag.*, vol. v, p. 534. Admits an earlier error as to the age of the Crayford beds.

18. 1869. Belgrand, E. "La Seine Le Bassin Parisien aux ages antehistorique," 3 vols. Paris. An important work that has been overlooked in recent years. Contains a very full account of the mammalia by Lartet, and of the mollusca by Bourguignat, with numerous plates. Prestwich reviewed this work and praised it highly. (*Nature*, March 14th, 1872.)
19. 1869. Tylor, A. "On Quaternary Gravels," *Quart. Journ. Geol. Soc.*, vol. xxv, pp. 57-100. An abstract of this appeared in the previous year under the title "On the Quaternary Gravels of England," *Quart. Journn. Geol. Soc.*, vol. xxiv, pp. 455-6. Reissued for private distribution as "A paper on Quaternary Gravels" with the same pagination, but on p. 100 a list of mammalia based on Dawkins [**12**] is added. A most important paper. There are five carefully measured sections of Erith and eight of Stoneham's pit. A plan of the latter is also given. Alfred Bell was responsible for the mollusca and many first records are given.
20. 1870-75. Sandberger, C. L. F. "Die Land und Süsswasser Conchy. der Vorwelt." On pp. 838-941 (1875) is a combined list from sixteen English localities of varying ages, including Crayford as Middle Pleistocene. Such lists are a hindrance and not a help to our knowledge. One species, *Planorbis dazuri* Mörch is recorded from Crayford.
21. 1872 Dawkins, W. B. "Brit. Pleist. Mamm.," Part V, *Ovibos moschatus* Zimm, *Mon. Palaeont. Soc.* The skull from Stoneham's is described and figured, a section is given showing its exact position and a list of associated mammals.
22. 1872. ————. "The classification of the Pleistocene strata of Britain and the Continent by means of the mammalia," *Quart. Journ. Geol. Soc.*, vol. xxviii, pp. 410-46. General Survey.
23. 1872. Fisher, O. "On a worked flint from the brickearth of Crayford," *Geol. Mag.*, vol. ix, pp. 268-9. Though he gives the locality as "Slades Green" from the description of the pit it is clearly Stoneham's. A list of mammalia by Dawkins is given. Dawkins was with Fisher when the flake was found. The first record of ***Homo***.
24. 1874. Catalogue of the Pleistocene Vertebrate from the neighbourhood of Ilford in Coll. Sir Antonio Brady. Privately printed. Section and references to Crayford.
25. 1874. Dawkins, W. B. "Cave Hunting," p. 416. Notes *Ovibos* at Crayford and states that the flint flake found by Fisher was from the same stratum.
26. 1874. Fisher, O. "On the antiquity of the worked flint from the Brickearth of Crayford," *Geol. Mag.*, Dec. 11, vol. i, p. 479, defends the Pleistocene age of the flake.
27. 1874. Woodward, H., and Davies, W. "Notes on the Pleistocene deposits. . . . . in the vicinity of Ilford, Essex, *Geol. Mag.*, Dec. 11, vol. i, pp. 390-403, pp. 392-3, extracts from a letter of S. V. Wood with reference to the relative ages of Grays, Ilford and Erith.
28. 1876. Cheadle, R. W. "On mammalian bones recently found at Crayford and Erith," *Proc. West Lond. Scientific Assoc.*, vol. i, pp. 70-71. First record of *Citillus* as *Spermophilus* from Erith.
29. 1876. ————"A tusk of mammoth found at Erith," *Proc. West Lond. Scientific Assoc.*, vol. i, p. 79. It was 22 ins. in greatest circumference, 75 ins. round the curve and from base to tip in a straight line 47 ins.
30. 1876. Cheadle, R. W. and Woodward, B. B. "Notes on the Pleistocene deposits at Crayford and Erith," *Proc. West Lond. Scientific Assoc.*, vol. i, pp. 92-8. Flint flake from Erith figured p. 96, list of mollusca with several new records.
31. 1877-1881. Adams, A. Leith. "British Fossil Elephants," *Mon. Palaeont. Soc.* Describes and figures bones and teeth of *Elephas antiquus* and *E. prim genius* from Slades Green, Erith and Crayford.
32. 1879. Davies, W. "On some recently discovered teeth of *Ovibos moschatus* from Crayford, Kent," *Geol. Mag.*, Dec. 11, vol. vi, p. 246. Describes four teeth of the lower jaw obtained by R. W. Cheadle from Stoneham's Pit at a slightly higher level than the skull.
33. 1880. Dawkins, W. B. "The classification of the Tertiary period by means of the Mammalia," *Quart. Journ. Geol. Soc.*, vol. xxxvi, pp. 379-405. List of mammals from Crayford-Erith, p. 398.
34. 1880. ————. "Early Man in Britain." On pp. 134-138 list of mammalia and references to the two flakes found by Cheadle and Fisher. Cheadle's figure [**30**] is copied as is also the section f. 31 from his own description of Ovibos [**21**].
35. 1880. Spurrell, F. C. J. "On the discovery of the place where Palaeolithic Implements were made at Crayford," *Quart. Journ. Geol. Soc.*, vol. xxxvi, pp. 544-8. Two sections, plate of restored block and figure of a flint *in situ*. The first record of a working site.

35a. 1880. Spurrell, F. C. J. “On implements and chips from the floor of a Palaeolithic Workshop.” *Arch. Journ.*, vol. xxxviii, pp. 294-9, 2 Plates, 1 section, and 1 text figure. Pl. I is identical with the Plate in No. 35; Pl. 2 figures other flakes, a small restoration and the “hache” from the large blocks. An overlooked paper.

35b. 1882. ———. “Notes on Prehistoric remains of man in the neighbourhood of Erith,” *4th Ann. Rep. Erith and Belvedere Nat. Hist. Soc.*, pp. 9-26. I have been unable to trace a copy of this rare paper.

36. 1882. Wood, S. V., Junr. “The Newer Pliocene Period in England.” *Quart. Journ. Geol. Soc.*, vol. xxxviii, pp. 676-7. Sections and theoretical views.

37. 1883. Arnold, G. M. Robert Pocock. The Gravesend Historian, etc. London.

37a. 1883. Spurrell, F. C. J. Palaeolithic Knapping Tools and modes of using them. *Jour. Anthrop. Inst.*, vol. xiii, pp. 109-118, a figure of a hammerstone from Stoneham's pit figured on Pl. III. An excellent account of the Crayford artefacts and details as to how they were probably made, based on personal attempts at flint working. There is also a full description of the working site at Ebbsfleet (Northfleet). The author suggests the term “turtle-backed scrapers” for the common Ebbsfleet (Northfleet) form. Though noted by W. Whitaker (44, p. 350) this paper has been overlooked in recent years.

37b. 1883. Spurrell, F. C. J. “Palæolithic implements found in West Kent.” *Archæologia Cantiana.* A resumé with references to Crayford.

38. 1883. Dawkins, W. B. “On the alleged existence of *Ovibos moschatus* in the Forest Bed, etc.” *Quart. Journ. Geol. Soc.*, vol. xxxix, pp. 575–81. Many references to the Crayford skull.

39. 1884. Dollfus, G. F. “Le terrain quat. d'Ostende et le *Corbicula fluminalis*.” *Mem. Soc. Roy. Malac. Belg.*, vol. xix, pp. 28–54. Three sections at Erith, lists of mammalia and mollusca, four examples of *C. fluminalis* from Erith figured. *Bos. longifrons* and *Hippotamus* recorded in error. These errors are only copied in Continental literature and are not found in English works.

40. 1885–7. Lyddekker, R. “Catalogue of Fossil mammalia in the Brit. Mus. (Nat. Hist.)” vols. 1–5. Descriptions of many Crayford bones in the collection but a very inadequate index.

41. 1885. Ridley, H. N. “*Castanea sativa* Müll., as a native of Britain,” Journ. Bot., vol. xxiii, pp. 253–4. Recorded from the Lower Brickearth, the only English Pleistocene record.

41a. 1885. Goodchild, J. G. “Notes on some superficial deposits of North Kent,” Proc. Geol. Assoc., vol. ix, pp. 151–160, Sections and theoretical views.

42. 1886. Spurrell, F. C. J. “A sketch of the History of the rivers and denudation of West Kent, etc.” *Report W. Kent Nat. Hist. Soc.*, pp. 1–54. Two plates of sections. A most important paper embodying the results of the author's life long work on the Pleistocene deposits of the lower Thames. Owing to its rarity it is too often overlooked.

43. 1889———“On the estuary of the Thames and its alluvium,” *Proc. Geol. Assoc.*, vol. xi, pp. 210–230. The best description of the Holocene beds of the lower Thames. Reference to *Elephas primigeniurs* dredged at Erith.

44. 1889. Whitaker, W. “The Geology of London,” *Mem. Geol. Survey*, vol. i, pp. 328–478. By far the best summary. Full descriptions of the deposits and many sections. Lists of mammalia by E. T. Newton, and the mollusca by E. T. Newton and B. B. Woodward. An indispensable work to the student.

45. 1890. Cockerell, T. D. A. “The Variation and abnormal development of the Mollusca,” *Science Gossip*, vol. xxvi, pp. 4–5, f. 9. A pathological specimen of *Pisidium amnicum* (Müll) from Crayford figured and described.

46. 1890. Newton, E. T. “On the occurrence of *Lemmus* and other rodents, in the brickearths of the Thames Valley,” *Geol. Mag.*, Dec. III., vol. vii, pp. 452–5. New records of Rodentia.

47. 1890. Woodward, A. S. and Sherborn, C. D. “Catalogue of British Fossil Vertebrates.” A critical summary of the published records.

48. 1890. Woodward, B. B. “On the Pleistocene N. M. Mollusca of the London District,” *Proc. Geol. Assoc.*, vol. ix, pp. 335–388. List of Mammals by E. T. Newton, p. 388. Six sections, a revised list of the mollusca and four species figured from Erith and Crayford. The block of the mollusca has been used several times (50) (60) (88). Hitherto the lists had been copied from earlier writers and this paper really marks the beginning of a new era.

49. 1891. Goodchild, J. G. "La Geologie d'Erith et de Crayford," *Congress Geol. Internat. Compte rendu de la 4me Session*, London, 1888, pp. 450–7. Sections and summary.

50. 1891. Holmes, T. V. and Sherborn, C. D. "A Record of Excursions," *Geol. Assoc.*, 1860–1890, pp. 16–25. Summarizes reports of excursions made in 1871. *Proc. Geol. Assoc.*, vol. ii, p. 229), 1872. (Vol. iii, p. 83). (Vol. iv, p. 323), 1879, (vol. vi, p. 174), 1885, (vol. ix, pp. 215, 216), 1890 ; (vol. xi, p. 144). Sections and figures of shells copied from 48.

51. 1891. Prestwich, Sir Joseph. "On the age formation and drift stages of the Darenth Valley," *Quart. Journ. Geol. Soc.*, vol. xlvii, pp. 152–3. Section of the railway cutting.

52. 1895. Kennard, A. S. "Pleistocene Mollusca of Crayford," *Science Gossip*, N.S., vol. ii, pp. 39–40. Three species figured.

53. 1896.————"*Unio littoralis* in Pleistocene Times," *Science Gossip*, N.S., vol. iii, pp. 118–119. A summary of its distribution.

54. 1897. Evans, Sir J. "Ancient Stone Implements," 2nd Edition. Notes the chipping floor at Stoneham's pit and three flakes but has mixed up the flakes found by Cheadle and Fisher.

55. 1899. Kennard, A. S. "Pleistocene Beds of Lower Thames Valley," *Science Gossip*, N.S., vol. vi, pp. 264-5. Summary.

56. 1900. Hinton, M. A. C. and Kennard, A. S. "Contributions to the Pleistocene Geology of the Thames Valley I., *Essex Nat.*, vol. xi, pp. 336–370. Many references to Crayford. First record of *Anser* sp.

57. 1900. Rutot, A. "Note sur la position statig. de la *Corbicula fluminalis* . . ." *Bull. Soc., Belge de Geol.* etc., vol. xiv, pp. 1–24. Two sections at Erith ; lists seven species of mammalia and repeats the errors of Dollfus (39). By combining several lists he records twenty species of mollusca including the error of *Hydrobia marginata*. The author was not acquainted with the English literature and no one now would accept his conclusion that Erith was older than the 30 m. terrace of the Oise France. He had visited Erith in 1899 with W. Whitaker (see 62).

58. 1900.————"Note sur la decouverte d'importants Gisements de Silex tailles . . . . comparison de ces silex avec ceux du Chalk-Plateau du Kent" Bruxelles, pp. 1–103, description with section of the beds and detailed account of the implements (pp. 91–103).

59. 1901. Johnson, J. P. "Palæolithic Implements from the low level drift of the Thames Valley," *Essex Nat.*, vol. xii, pp. 52–7. Two implements from Crayford figured. The Ilford specimens figured are in the museum of the Essex Field Club at Stratford, E.

60. 1901. Kennard, A. S., and Woodward, B. B. "The Postpliocene non-marine mollusca of the South of England," *Proc. Geol. Assoc.*, vol. xvii, pp. 213–260 and tables. Revision of the mollusca.

61. 1901. Newton, E. T. "British Pleistocene Fishes," *Geol. Mag.*, Dec. IV., vol. viii, pp. 49–52. Records teeth of Pike in coll., B. B. Woodward and Geol. Mus 5646 (Spurrell Coll.).

62. 1901. Rutot, A. "Compte rendu de la session annuelle extra. de 1899 tenue dans le Bassin de Londres. *Mem. Soc., Belg. de Geol.* vol. xiii, fasc. 2, p. 267, describes the excursion to and the beds at Erith.

63. 1902. Reynolds, S. H. "Mon Brit. Pleist Mamm," (*Palaeont Soc.*), vol. ii., *Hyaena*. Recorded from Crayford.

64. 1902. Johnson, J.P. "The Palæolithic Period in the Thames Basin," *Essex. Nat.* vol. xiii, pp. 97–110. Two implements from Crayford figured already given in 59.

65. 1903. Pocock, T. I. "On the drifts of the Thames Valley near London." *Summary of Progress of the Geol. Survey for* 1902, pp. 199–207. Summary (pp. 205–6).

66. 1903. Rutot, A. "Esquisse d'une comparison des couches Pliocene et Quat. de la Belgique avec celles du Sud-est de l'Angleterre," *Bull. Soc. Belg. de Geol.*, vol. xvii, pp. 57–101. On p. 70 states that a large number of molars of *Elephas antiquus* have been found at Erith whereas it is very rare. This error is copied from Boyd Dawkins (10 p. XXXV.).

67. 1905. Hinton, M. A. C. and Kennard, A. S. "The relative ages of the stone implements of the Lower Thames Valley," *Proc. Geol. Assoc.*, vol. xix, pp. 76–100. The Crayford industry claimed to be "Moustier."

68. 1905. Kennard, A. S., and Woodward, B. B. "The Extinct Post-pliocene non-marine mollusca of the South of England," *South-Eastern Naturalist*, pp. 14–24. New records and references to other species.

69, 1905. Leach, A. L. "Excursion to Erith and Crayford," *Proc. Geol. Assoc.*, vol. xix, pp. 137–141. Five new sections.

70. 1906. Reynolds, S. H. "Mon. Brit. Pleist. Mamm." (*Palaeont. Soc.*). vol. ii, Bears. Part of cranium of *Ursus arctos* Linné, figured.

71. 1907. Hinton, M. A. C. "On the existence of the Alpine Vole (*Microtus nivalis*) in Britain in Pleistocene times." Ten microtine teeth from Crayford figured and described.

72. 1908. Haas, F. "Ein Neuer Fossiler Unio" *Nachrbl. Deutsch. Malak. Gesell.*, xl, pp. 177-8. *Unio Kinkelini* Haas from the Pleistocene of Mosbach and Biebrich Germany = *Psilunio littoralis* (Cuvier) var.

73. 1909. Reynolds, S. H. "Mon. Brit. Pleist. Mamm" (*Palaeont. Soc.*), vol. ii, Canidae. Records only.

74. 1909. Salter, A. E. "A Survey and Record of Woolwich and W. Kent," edited by C. H. Grinling and others, pp. 20-22. Summary and reference to the record of *Castanea sativa*, p. 37.

75. 1910. Hinton, M. A. C. "A preliminary account of the British Voles and Lemmings," *Proc. Geol. Assoc.*, vol. xxi, pp. 489-507. Summary of the microtine fauna.

76. 1912. Bromehead, C. N. "On diversions of the Bourne near Chertsey." *Summary of Progress of Geol. Survey for* 1911, pp. 74-77 Proposes the terms Boyn Hill for 100 ft. Terrace and Taplow, for 50 ft. Terrace.

77. 1912. Chandler, R. H. and A. L. Leach. "Report of an Excursion . . . . Pleistocene River Drifts near Erith." *Proc. Geol. Assoc.*, vol. xxiii, pp. 183-190. Two sections and three photographs of sections.

78. 1913. Woodward, B. B. "Catalogue of the British species of Pisidium." References to Crayford specimens and many figured.

79. 1914. Chandler, R. H. "The Pleistocene Deposits of Crayford," *Proc. Geol. Assoc.*, vol. xxv, pp. 61-71. Two sections and two photographs of sections.

80. 1914. Higgins, R. Brice. "Flint Implements of Moustier type and associated mammalian remains from the Crayford Brickearth," with note by R. A. Smith. *Man*, vol. xiv, pp. 4-8 and p. 31.

81. 1915. Holst, N. O. "The Ice Age in England," *Geol. Mag.*, Dec. VI, vol. ii, pp. 418-424, 434-44, 594-13. On pp. 435-6 summary of evidence and conclusion that Crayford is the equivalent of Hofstade Belgium i.e. Campinien.

82. 1915. Keith, A. "The Antiquity of Man," section and summary, pp. 103-8.

83. 1915. Kennard, A. S. and Woodward, B. B. "On Helicella (Candidula) *crayfordensis* n. sp. from the Pleistocene deposits of South Eastern England," *Proc. Malac. Soc. Lond.*, vol. xi, pp. 270-1. Figured. = *radigueli* (Bourg), 1869.

84. 1916. Chandler, R. H. "The implements and cores of Crayford," *Proc. Prehist. Soc. E. Anglia*, vol. ii, pp. 240-8. Eight figures of flakes and cores.

85. 1916. Kennard, A. S. "The Pleistocene Succession in England," *Proc. Prehist. Soc. E. Anglia*, vol. ii, pp. 249-267. Summary pp. 255-7.

86. 1918. Stelfox, A. W. "The Pisidium fauna of the Grand Junction Canal." *Journ. of Conch.*, vol. xv, pp. 289-304. *P. parvulum* Auct non Clessin, recorded from Crayford and the new trivial name of *torquatum* proposed = *moitessierianum* Paladilthe.

86a. 1921. Macalister, R. A. S. A Text Book of European Archaeology, vol. i. The Palaeolithic period. Several references.

87. 1922. Dewey, H. *Summary of Progress of the Geol. Survey for* 1921, p. 8, proposes the names of Swanscombe for the High Terrace and Crayford for the 50 ft.

88. 1922. Kennard, A. S. and Woodward, B. B. "The Post-pliocene non-marine Moll. of the East of England," *Proc. Geol. Assoc.*, vol. xxxiii, pp. 104-142. *Paladilhia radigueli* (Bourg) recorded from Crayford, p. 137 = *Hydrobia ventrosa* Auct. vet.

89. 1924. Geology of Country around Dartford, *Mem. Geol. Surv.*, Sheet 271. Excellent summary by C. E. N. Bromehead, pp. 99-101.

90. 1924. Kennard, A. S. "The Pleistocene non-marine mollusca of England," *Proc. Malac. Soc. Lond.*, vol. xvi, pp. 84-97. Many references to Crayford.

91. 1924. Hinton, M. A. C. "Rivers and Lakes." London. General summary p. 65-68.

92. 1925. Kennard, A. S., Salisbury, A. E. and Woodward, B. B. "Notes on the British Post-Pliocene *Unionidae*," *Proc. Malac. Soc. Lond.*, vol. xvi, pp. 267-285. *Unio* (*Psilunio*) *littoralis* Cuvier from Crayford figured Pl. XX, Figs 8, 9, 11.

93. 1926. Hinton, M. A. C. "Monograph of the Voles and Lemmings," vol. i. References to and figures of Crayford specimens. First records of *Dicrostonyx gulielmi* (Sanford) and *Microtus malei* Hinton.

94. 1926. ————. "The Pleistocene Mammalia of the British Isles, etc." *Proc. Yorks. Geol. Soc.*, N.S., vol. xx, pp. 325-348. An all too brief account of the mammals (pp. 338-340).

94a. 1926. Digby Bassett. "The Mammoth," London. A "popular" work but on a much higher scientific level than is usual with so-called popular books. It gives a fairly complete resumé of our knowledge of the mammoth coupled with first hand information of its presence in Siberia.

95. 1928. Franz, V. "Paludinen Studien," *Bibliotheca Genetica*, Band XI, *Viviparus menzelii* n. sp. described and figured, pp. 125-6, Figs. 23-24.

96. 1929. Reynolds, S. H. "Mon. Brit. Pleist. Mamm," vol. iii, pt. 3. The Giant Deer (Palaeont. Soc.). Recorded from Erith.

97. 1929. Wenz, W. "Zur Gesch. u. Verbreit. des *Pisidium clessini* Neumayr = *astartoides* Sandb. *Arch. Moll.*, vol. lxi, pp. 185-9.

98. 1931. Breuil, H. "The Pleistocene sequence in the Thames Valley," *South-Eastern Naturalist and Antiquary*, vol. xxxvi, pp. 95-8. Summary.

99. 1931. Dewey, H. "Palaeolithic Thames Deposits," *Proc. Prehist. Soc. East Anglia*, vol. vi, pp. 147-155. Summary.

100. 1931-2. Breuil, H. and Koslowski. "Etudes de statig. Palaeolith. dans le nord de la France. la Belgique et l' Angleterre," *L' Anthropologie*, vol. xli, pp. 449-488, vol. xlii, pp. 27-47, and pp. 291-314. Summary.

101. 1932. Sandford, K. S. "Some recent contributions to the Pleistocene Succession in England." *Geol. Mag.*, vol. lxix, pp. 1-18. Summary. On pp. 17–18 two letters from H. Breuil on Crayford.

102. 1933. Boswell, P. G. H. "The contacts of Geology, etc.," *Brit. Assoc. Report for* 1932, pp. 57-88. Summary.

103. 1933. Reynolds, S. H. Mon. Brit. Pleist. Mamm. (*Palaeont. Soc.*), vol. iii, pt. 4. "Red deer, Reindeer and Roe." Red deer recorded.

104. 1934. Baden Powell, D. F. W. "On the marine gravels at March, Cambridgeshire," *Geol. Mag.*, vol. lxxi, pp. 190-219. *Corbicula consobrina* (Caill.) stated to be the correct name of the Pliocene and Pleistocene *Corbicula*.

105. 1934. Reynolds, S. H. "Mon. Brit. Pleist. Mamm." *Ovibos*, suppl. (*Palaeont. Soc.*). The four teeth from Crayford found by Cheadle (32) figured.

106. 1935. Burchell, J. P. T. "Some Pleistocene deposits at Kirmington and Crayford," *Geol. Mag.*, vol. lxxii, pp. 327-331. The latter locality is an errro for Ebbsfleet.

107. 1936. Franz, V. "*Viviparus menzelii* Franz, etc.," *Arch. Moll.*, vol. lxvii, pp. 142-167, Pl. 7 and 8.

108. 1936. King, W. B. R. and Oakley, K. P. "The Pleistocene Succession in the lower parts of the Thames Valley," *Proc. Prehist. Soc.*, pp. 52-76. A most useful summary.

108a. 1936. Boycott, A. E. "The habitats of Freshwater Mollusca in Britain." *Journ. Animal Ecology*, vol. v, pp. 116-186. The results of a life study of the subject.

109. 1936. Chandler, R. H., and Leach, A. L. "A glacially striated Sarsen Boulder from Pleistocene River Drift near Erith," *Proc. Geol. Assoc.*, vol. xlvii, pp. 249-253, Plates of sections, and of the striation of the Sarsen.

110. 1939. Moir, J. Reid, and Hopwood, A. Tindell. "Excavations at Brundon, Suffolk," *Proc. Prehistoric Society*, pp. 1-32. Many references to and measurements of Crayford bones by Dr. Hopwood. A paper of great importance.

110a. 1939. Schalie H. van der. "*Hendersonia occulta* (Say) in Michigan, its distribution, ecology and geological significance." *Occ. Pap. Mus. Zool. Univ. Mich.*, 399, pp. 1-18, 1 plate. The author concludes that during the deposition of the loess the climate was damper and warmer.

111. 1939. Reynolds, S. H. "Mon. Brit. Pleist. Mamm.," vol. iii, pt. 6, Bovidae (*Palaeont. Soc.*). *Bos. primigenius* and *Bison priscus* recorded.

112. 1940. Hopwood, A. T. "Fossil Mammals and Pleistocene correlation." *Proc. Geol. Assoc.*, vol. li, pp. 79-88. Many references to Crayford.

113. 1942. Bull, A. J. "Pleistocene Chronology," *Proc. Geol. Assoc.*, vol. lii, pp. 1-45. This paper with the symposium contributed by seventeen other workers is a most valuable one. There are many references to Crayford, whilst Day Kimball's account of the various "benches" there is of great importance.

DISCUSSION.

Mr. A. D. Lacaille: The presence of hand-axes with flake-implements gives archaeological support to the President's contention for the genial conditions attested by the Crayford brick-earths. It is by now well established that in the Lower Palaeolithic cultures hand-axes are typical of the warmer periods, and flake-implements of the colder. Such associations, however, obtained much longer. On Continental standards, the facies of the flakes and hand-axes from the Crayford brickearths is Levalloisian, almost at the peak of its development. In their situation these artifacts appear to be the counterparts of the evolved Levalloisian forms occuring in late Riss-Würm deposits in river valleys in the north of France and Belgium, that is to say in a stage paralleled by the " warm " Mousterian of south-western France, rich in hand-axes though basically a flake-culture.

English deposits, referable to a phase immediately preceding that during which the Crayford brickearths were laid down, contain implements held to represent the highest expression of Acheulian culture. The problem of human contacts and the blending of industries, therefore, arises. By his exemplary researches Mr. Kennard has shown the methods by which it will be solved.

Dr. K. P. OAKLEY said that all future research on the Middle Terrace deposits of the Thames Valley would need to take into account this monumental paper on the Crayford Brickearths, which represented a compilation and assessment of facts gathered over a period of more than fifty years.

Mr. Kennard's analysis of the molluscan evidence seemed to leave no doubt that the Corbicula Bed was part and parcel of the Lower Brickearth, and that the whole had been laid down under more genial conditions than one had generally associated with the name musk-ox. Shell-size could evidently be correlated with climatic conditions, and the largeness of the Anodons and snails in the brickearths seemed to imply a climate warmer than that which we now "enjoy." Such a criterion was more reliable for assessing the climate under which a deposit had accumulated than the present distribution of types represented in that deposit. From the present distribution of *Elephas* (s.l.) one might have reached the conclusion that all elephants were restricted to warm climatic conditions ; yet in the light of the Siberian evidence it was an inescapable fact that in the Pleistocene at least one species became inured to tundra. Could we be certain that because the mammoth was able to withstand cold that he would have been killed off by the resumption of genial conditions ? No. And the same might be said about the musk-ox, the woolly rhinoceros and the snow-vole (in fact perhaps even about the reindeer). If one admitted that these creatures were adaptable enough to have survived under genial conditions, then none of the facts enumerated by Mr. Kennard presented any difficulty to the geologist, for whom boulder clays were facts just as stark as molluscan shells, and who therefore accepted the European Pleistocene as polyglacial. No facts had been brought forward that were inconsistent with the view that the lemmings, mammoth and the rest of the " cold-indicators " in the Crayford Brickearths represented local survivals from a preceding cold phase to which they had been more specially adapted.

Mr. Kennard had said that warm-blooded animals would naturally prefer a warm climate. But if mere economy had been an overriding factor in evolution, progress would scarcely have been possible. The acquisition of warm-bloodedness was surely a step in the direction of emancipation from evironment. Reptiles were far more dependent on external temperature than creatures with internal thermostatic heating. It was their high metabolic rate which enabled mammals to remain active under intensely cold conditions.

Current views on the conditions under which the Lower Crayford Brickearth had been laid down might need revision in the light of Mr. Kennard's findings, but at any rate his conclusions removed one outstanding difficulty in correlating Thames and Somme. Archaeologically this brickearth was the correlative of deposits in the 10-metre Terrace of the Somme with warm fauna and Middle Levalloisian industry as at Menchecourt. Thus the " cold " character of the Lower Crayford Brickearth had long been regarded by archaeologists as anomalous.

The Upper Crayford Brickearth may be a sludge of the same age as the Coombe Rock of Ebbsfleet (Northfleet) ; if so it would at any rate remove certain difficulties in the indentification of the Baker's Hole Industry (vide *Trans. S.E. Union Sci. Soc.*, 48, 1943, p. 31), but it would involve returning part of the Thames Succession once more to the " melting-pot."

Few would deny that there was a considerable amount of water about at the time of accumulation of some coombe deposits, but the typical calcareous coombe rock was made up of irregular lumps of chalk set in a finer matrix, and no amount of rainfall would reduce the chalk to such a heterogeneous condition. One can only suppose that the final sludging of the material had been due to a general melting following a period of intense freezing and seasonal partial thawing which had disintegrated the Chalk to a considerable depth. On gentle slopes extensive sludging presupposed a practical absence of vegetation.

In regard to Mr. Kennard's comments on mollusca from coombe deposits and loess : it seemed improbable that shells found in such deposits were wholly representative of the conditions of formation. Thus, mollusca probably colonised pools formed on the surface of loess or solifluction terrain when mild conditions had temporarily intervened, and such faunules could scarcely be expected to reflect the climatic rigours associated with actual accumulation of loess or disintegration of the sub-soil which preceded the solifluction. Was it not likely that even during the maxima of glaciation there were favoured spots in and beyond the periglacial zones where " micro-climates " enabled the interglacial species of mollusca to hang on, ready to spread widely at the first favourable opportunity ?

THE AUTHOR wished to thank the various speakers for their kind reception of an heretical paper. In reply to Dr. K. P. Oakley that the mammoth was a cold indicator he could only repeat the opinion of Dr. Falconer that it was not. It is very probable that the oncoming of tundra conditions plus man was the cause of its extinction in Siberia. All sorts of deposits have been called a " Boulder " clays and even the Pliocene beds of St. Erth were termed glacial by one over-enthusiastic glaciologist. He considered it better to ignore all theories especially German, and to collect all the facts, make deductions and leave it at that. In Pleistocene geology we have had " a vast return of theory for a small investment of fact." " Prove all things " is the motto of the scientific worker.

AN UNUSUAL VARIETY OF FLINT FROM NEAR BURNHAM, BUCKINGHAMSHIRE

By KENNETH P. OAKLEY, Ph.D.

[*Received 4th December*, 1943.]
[*Read in Abstract*, 31*st March*, 1944.]

MR. A. D. LACAILLE, F.S.A., recently submitted for geological determination a humanly worked block of siliceous stone which had been found at a depth of 9 feet in the gravels of the Lower Boyn Hill (Furze Platt) Terrace at Lent Rise, near Burnham, Bucks. It is a bluntly pointed bifacial hand-axe, only very slightly rolled, and by style of flaking referable to the Middle Acheulian industry of the Lower Palaeolithic term. It is 15 cms. long, 10.7 cms. wide, with maximum thickness, towards the base, of 7.3 cms. One face is strongly convex, retaining a knob of original cortex ; the other face (shown in Fig. A of Plate 8) is less convex and flaked all over. The butt is truncated by a flat area (*x* in Fig. C), which is covered by a film of chalcedony and is evidently an original joint plane. The workmanship appears crude, but this is attributable to the poor flaking quality of the raw material, not to lack of skill on the part of the craftsman, who was perhaps attracted more by the unusual appearance of the stone than by its tractability. Finely shaped Middle Acheulian hand-axes of flint abound in the gravels in which the specimen was obtained [**1***].

The chief interest of the specimen undoubtedly lies in its unusual lithology. Cursory inspection gives the impression of a siliceous conglomerate of flint pebbles, but closer examination shows that it is a nodular cherty flint containing pebble-like inclusions. The flint is basically dark grey in colour ; the flaked surfaces are barely patinated, but have been stained yellowish-brown through absorption of ferruginous solutions. The inclusions are picked out in lighter hue than the matrix ; they vary in form from subangular flecks or lumps to perfect ovoids, and in diameter from 0.5 mm. to 1.5 cms. They lie at all angles to the bedding-plane, indicated by the general form of the nodule.

That the specimen consists of a single nodule of Cretaceous flint, and is not a Tertiary conglomerate of flint pebbles, such as the Hertfordshire Pudding-stone, is proved by the fact that the siliceous groundmass is riddled with the hollow moulds of Cretaceous echinoderm fragments. These moulds, which give the stone a carious structure, mostly represent broken and slightly rolled Cidarid plates and spines, e.g. *Tylocidaris clavigera* (Koenig) and *Cidaris serrifera* Forbes ; and asteroid ossicles, including *Metopaster parkinsoni* (Forbes). See Plate 8, Figs. B, C.

Thus, there appears to be no doubt that the pebble-like inclusions are an internal structural feature of the flint nodule. Yet their boundaries are too sharply defined to be due to patchy crystallization of the silica-gel, such as may be held to account for the normal cherty patches in flint, and it seems probable that they represent structures antedating the formation of the nodule.

Flint is now generally regarded as a replacement of chalk, at the earliest epigenetic in relation to the latter [**2** and **3**]. Certainly no other view of its origin would seem competent to explain the structure of this particular nodule, which has every appearance of being a siliceous replacement of a fine conglomerate, or pellet-bed in the Chalk. Apart from the remote possibility that it represents the spewed-out meal of an echinoderm-eating animal, the concentration of corroded echinoderm fragments in the material would seem to indicate just those conditions of local scouring of the sea-floor which would re-work partly hardened sediment into pellets. It might be suggested, of course, that the inclusions represent a primary generation of flint, broken up by pene-contemporaneous erosion, and set in a shelly calcareous matrix which underwent silicification during the formation of a later, secondary generation of flint. It is difficult to see how flint could be eroded into pebbles in the absence of abrasive sediment. The eroded form of the larger inclusions is thus more consistent with the simpler explanation that they originated through siliceous replacement of chalk pellets. Although pellet-beds are moderately common in the English Chalk, there is no recorded instance of one containing eroded flint. Even more significant in this connection is the absence of eroded flint from the intra-formational conglomerates in the flint-bearing Chalk of Mons [**4**].

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* For List of References see p. 171.

That there is some textural difference between the silicified inclusions and their matrix, however, is shown by the selective iron staining which has taken place ; also by the fact that in the corroded cortex the inclusions have weathered away to a greater extent than the groundmass. All that this may indicate is that silicification of pellets and matrix took place in separate stages, which could be accounted for by difference in relative solubility.

The fact that the echinoderm remains are represented by hollow moulds is in accordance with Wroost's thesis [**5**] that the replacement of chalk by silica-gel, following downward percolation of carbonated water bearing silica-sol, is mainly controlled by differential solubility. Macrocrystalline calcite structures such as echinoderm tests, being less soluble than compacted chalk mud, tended to escape silicification, but were liable to subsequent removal if non-siliceous waters with free CO_3-ions eventually obtained access to them. Under the conditions of formation of the nodule we are considering the macrocrystalline calcite structures were evidently less readily soluble than either the compacted chalk mud or the harder chalk pellets which that appears to have enclosed, and thus remained unreplaced by silica.

The echinoderm assemblage in the flint suggests derivation from the *coranguinum* zone. No pellet-bed appears to have been recorded in that zone but the occurrence of phosphatic layers in the *Conulus* subzone of Buckinghamshire [6] may indicate[1] a shoaling of the sea in that region towards the end of the *coranguinum* hemera, and such might well have brought the sea-floor locally under the influence of currents resulting in the formation of a pellet-bed as yet unrecognized *in situ*.

I am grateful to Mr. Lacaille for drawing my attention to this interesting specimen, which he has now presented to the British Museum (Natural History), and also to Mr. R. Melville for identifying the asteroid ossicle figured in Plate 8, Fig. C.

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[1] Decrease in depth tends to upset the equilibrium of bottom waters in respect to phosphorus and so leads in some circumstances to the precipitation of calcium phosphate ; there is no implication that phosphatic deposits are of shallow-water origin, or that they have all been formed in this way. See address in forthcoming *Trans. S.E. Union Sci. Soc.* (for 1944).

EXPLANATION OF PLATE 8.

A.—Palaeolithic hand-axe (Middle Acheulian) : flaked from nodule of flint apparently formed by silicification of pellet-bed (probably in *coranguinum* zone). From gravels at Lent Rise, near Burnham, Bucks. B.M. (G.D.) *E.* 1001.

(Note. The large, rounded light-coloured patch on the right is not one of the pebble-like inclusions ; it is a truncated horn of the nodule showing the cherty structure common to the sub-cortical layer of many flints.)

B.—Fractured surface of the flint showing mould of radiole of *Tylocidaris clavigera* (Koenig) and a typical pebble-like inclusion. [Same scale as C.]

C.—Fractured surface of the flint showing pebble-like inclusions and carious structure due to solution of unreplaced echinoderm fragments. N.B. mould of supero-marginal ossicle of *Metopaster parkinsoni* (Forbes) indicated by arrow, and, to 'N.E.' of it, mould of radiole of *Tylocidaris clavigera* (Koenig). The flat area forming the base of the hand-axe, apparently a vertical joint plane, is marked by *x*.

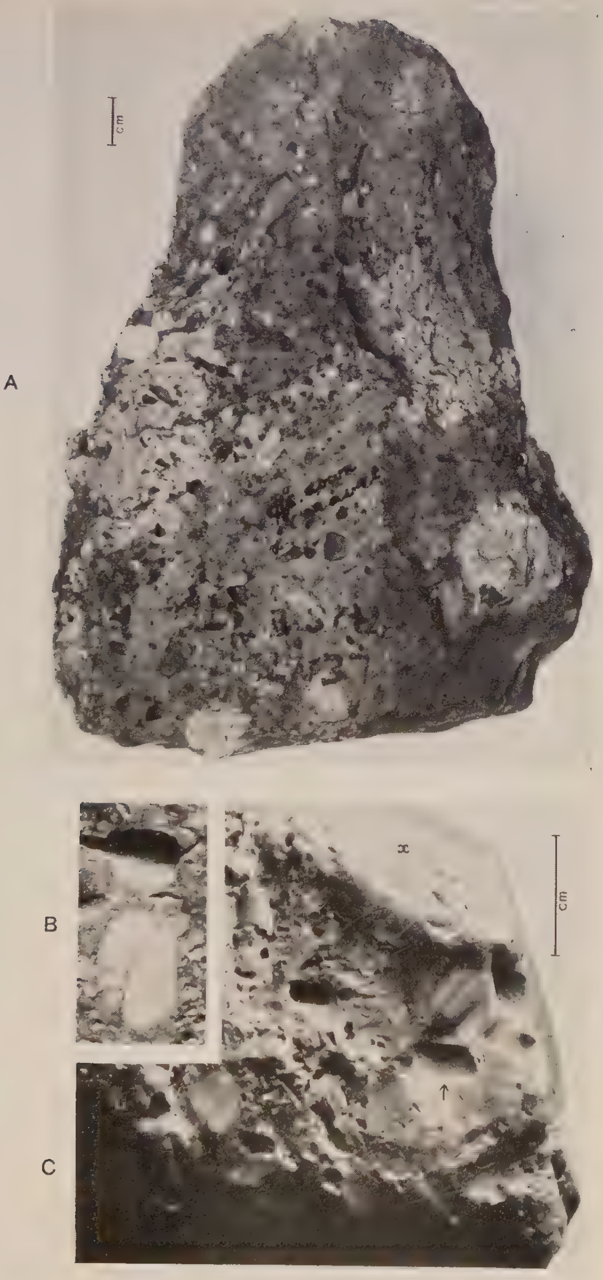

Photo: M. G. Sawyers.

Unusual variety of flint (replaced pellet-bed ?) from near Burnham, Bucks.

[*To face* p. 172.

THE STRATIGRAPHY OF THE CHALK OF SUSSEX.

PART III. WESTERN AREA.—ARUN GAP TO THE HAMPSHIRE BOUNDARY, WITH ZONAL MAP.

By CHRISTOPHER T. A. GASTER, F.G.S.

[*Received 4th January*, 1944.]
[*Read in Abstract, 7th July*, 1944.]

INTRODUCTION.

THIS paper comprises the third part of an extensive survey of the Chalk of Sussex. It records the result of a survey of the Chalk in the area extending from the Arun Gap to the Hampshire boundary, a distance of 16½ miles. The width of the outcrop from the main escarpment on the north to the Coastal Plain on the south ranges from 4 to 7 miles.

The area dealt with is included in parts of Sheets 316 (Fareham) and 317 (Chichester) of the Geological Survey. The three major divisions of Lower, Middle and Upper Chalk shown on those Sheets are replaced in the present work by detailed zonal results as recorded on the accompanying Map (Pl. 9).

Reference to the Survey Memoirs indicate that research on the Chalk of this part of the county has been scanty. This is probably due to the many large estates and tracts of woodland covering the Downs, and to the limited means of access in the past to this purely rural area.

The trend of the main escarpment is E.S.E. to W.N.W. with the exception of a break west of Bignor due to the influence of an anticline which enters the Downs at that spot. The course of this folding is indicated on the map by a tongue of Chalk zones running east to west through Up Waltham and along the Lavant Valley as far as West Dean. The anticline then turns in a S.W. direction to Bow Hill and terminates at Walderton Down. It is proposed to refer to this anticline as the "Singleton Anticline." The Chalk of the *Holaster subglobosus* zone, which outcrops at Up Waltham, and previously recorded as an inlier, is now shown to form part of the main outcrop. In the area of the axis of the anticline at Singleton is an inlier of chalk of the *Inoceramus labiatus* zone, where the top of this zone occurs at about 230 ft. O.D. The presence of an inlier of Chalk of the *Marsupites* zone on the N.W. limb of this anticline at Bow Hill substantiates Mr. H. J. Osborne White's view that this zone came to the surface hereabouts, and that the mapping of Middle Chalk by the Survey on Sheets 316 and 317 at Stoughton is an error [**12***, p. 32]. The mapping of an inlier of Middle Chalk south of Chilgrove on Sheet 317 is also incorrect. Here the outcrop again includes Chalk of the *Marsupites* zone.

The syncline associated with the Singleton Anticline runs along on the north side of the anticline and terminates in a S.W. direction in the Upper Ems Valley, N.W. of Walderton Down. This syncline will be referred to as the "Littlewood Syncline." Evidence shows the axis of the syncline to run through Littlewood Farm and the south end of Littlewood Common, one mile north of Singleton Village.

The influence of the Singleton anticline through the Lavant valley is responsible for a change of dip in the area between East Dean Hill and West Dean Park, consequently twisting the strata at East Dean Hill as shown by the base line of the *Marsupites* zone.

The folding at Torberry Hill, Harting, referred to by Mr. Osborne White [**12,** p. 63] does not exist, but a local flexure occurs in the neighbourhood of the main escarpment between Treyford and East Harting, which is indicated on the accompanying map by the position of the Melbourn Rock, and the Chloritic Marl in that locality. A change of dip also diverts the strike of the Chalk as illustrated by the base line of the *Holaster planus* zone at 700 ft. O.D., which runs from Bepton Down westward to Treyford Hill and is then taken to another line at that level from Pen Hill to West Harting Down.

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* For List of References, see p. 188.

It has already been mentioned that the width of the outcrop varies from 4 to 7 miles. This is due to folding causing variations in the dip. For instance, the 7 miles width includes a gentle dip of less than 1° at Harting, and a dip of 1° in the Stansted Park and Forest area. The dip between these two localities ranges from 3° to 5°. The shallow dip at Harting may be due to some obscure flexures mentioned by Mr. Osborne White [**12**, p. 62] and also to the flexures between Treyford and East Harting referred to in the last paragraph. The dip of 1° in the Stansted Park and Forest area is no doubt due to the folding to the east at Stoughton (i.e. the Singleton anticline and Littlewood syncline) and south to the influence of the Portsdown anticline and Chichester syncline. (See sketch map showing lines of folding [**12**, p. 62]—delete syncline at Torberry Hill).

The feature referred to as the secondary escarpment in Parts I and II [**4**, p. 357 and **5**, p. 512] is again illustrated on the accompanying map by the course followed by the outcrop of the *Marsupites* Chalk. The direction of this structure facing east between Chilgrove and Kingley Vale is due to the Singleton anticline. Elsewhere the secondary escarpment is facing north and runs along the Downs in the direction of the normal strike. The feature is continued into Hampshire at Chalton and then westward as recorded by Mr. Osborne White [**12**, p. 66].

In Sussex it is convenient to divide the chalk zones into two groups : (a) Main escarpment zones comprising the zones of *Schloenbachia varians* to *Micraster coranguinum*, and (b) secondary escarpment zones including the zones of *Marsupites testudinarius*, *Offaster pilula* and *Actinocamax quadratus*.

The feature caused by the Singleton anticline from Up Waltham along the north side of the Lavant Valley to West Dean will thereupon qualify as a main escarpment feature.

Another feature to which reference should be made is the gaps in the crest of the main escarpment which occur at the upper ends of the long dip-slope Valleys from Treyford westward into Hampshire as far as Butser Hill. In his report of the Field Meeting in West Sussex in 1938 [**6**, p. 163] the author suggested that the crest line was held by the hard chalk of the zones of *Holaster planus* and *Micraster cortestudinarium* and that where these zones had been pierced by denudation a more rapid rate of erosion of the softer Chalk below would set in, and produce these gaps in the escarpment [see also **12**, pp. 66, 67].

Outliers of zones are :

Holaster planus zone, Barlavington, Down.
Terebratulina lata zone, Farm Hill, South of Barlavington Down.
Micraster corangiunum zone, North of Lavant Valley between East Dean and Singleton.
Holaster planus zone, Pen Hill and S.S.E. of Pen Hill, south of Elsted.
Holaster planus zone, Round Hill, Harting Downs.
Holaster subglobosus zone, Torberry Hill, Harting.
Inoceramus labiatus zone, Hemner Hill, Harting.
Micraster cortestudinarium zone. West Harting Down.
Actinocamax quadratus zone
South of White Horse Inn, Chilgrove.
S.W. of Chilgrove Manor.
Wildham Wood, south of East Marden Down.
Lambdown Hill, Stoughton.
West Stoke.
Between Compton and Stoughton.

The outlier of Upper Chalk at Farm Hill shown on Sheet 317 (Chichester) of the Survey does not exist.

Inliers of zones are :

- *Marsupites* zone, Dale Park, Madehurst.
- *Inoceramus labiatus* zone, Singleton.
- *Micraster coranguinum* zone, Selhurst Park.
- *Micraster coranguinum* zone, west of Selhurst Park.
- *Micraster coranguinum* zone, Hayes' Down, north of Lavant.
- *Micraster cortestudinarium* zone, Bepton Wood, South of Linch Down, Bepton.
- *Holaster planus* zone, Linchball Wood, south of Linch Down, Bepton.
- *Inoceramus labiatus* zone, West Harting Down.
- *Terebratulina lata* zone, West Harting Down.
- *Marsupites* zone, N.W. slope of Bow Hill, Stoughton.

As already stated neither the inlier of Lower Chalk at Up Waltham shown on Sheet 317 (Chichester) of the Survey, nor the inliers of Middle Chalk, south of Chilgrove and west of Bow Hill, Stoughton, also shown on that Sheet, and on Sheet 316 (Fareham), exist.

The highest points in the district are Crown Tegleaze 837 feet and Linch Ball 818 feet. In both places occur an outcrop of the basement beds of the *Micraster corangiunum* zone.

The classification and general description of the various zones of the Chalk recognised in Sussex are contained in Part I of this work [**4**, pp. 359-363]. Further details of the zones of *Offaster pilula* and *Actinocamax quadratus* were recorded by the author in 1941 [**7**, pp. 210-215].

As the index fossil of the zone of *Terebratulina lata* is a common fossil at the top of that zone, and *Holaster planus* is also common at the base of the *Holaster planus* zone in the district, zonal evidence for the junction line between these two zones was secured wherever possible.

The zonal mapping of the Chalk in the area has been accomplished on palaeontological evidence only, strike and dip being established on this evidence.

An important strike line at 400 ft. O.D. was ascertained for the base of the *Uintacrinus* subzone, extending from Stapleash Down, West Dean, to Chalton in Hampshire, a distance of over six miles. Evidence for this in Hampshire was obtained in Huckwood Lane, Idsworth, at 320 ft. O.D. 70 yards east of Old Chalk Pit and at intervals for 400 yards eastward in banks of lane ; also at 360 ft. O.D. on the south side of road at Chalton Peak, 400 yards east of Chalton Church. Brydone in his zonal map of the Hampshire Chalk published in 1912 [**1**] placed this Chalk in the *Micraster coranguinum* zone, and he records the base of the *Uintacrinus* subzone, threequarters of a mile south of the author's line.

Further discrepancies in Brydone's mapping were found in Pits Nos. 1023, Blendworth Down, and No. 1024, Blendworth [**1**, p. 96]. Brydone placed these two pits in the subzone of *Echinocorys scutatus* var *depressa* of the *Offaster pilula* zone, but on examination the author was able to definitely place both pits in his zone of *Actinocamax quadratus*. the Chalk being over 100 ft. higher than Brydone's determination. It is obvious from these and other results, and to differences in the thicknesses of the various zones, that the author's zonal boundary lines do not join with Brydone's lines at the Hampshire border.

Fortunately a large amount of substantial evidence was obtained to enable the author to estimate with considerable accuracy the thickness of each zone in the area, and the following results have been established :

		Feet.
SENONIAN	Zone of *Actinocamax quadratus*	150
	Zone of *Offaster pilula*	165
	(a) Subzone of *Echinocorys scutatus* var. *cinta* (105 ft.)	
	(b) Subzone of *Echinocorys scutatus* var. *depressa* (60 ft.)	
	Zone of *Marsupites testudinarius*	100
	(a) *Marsupites* subzone (50 ft.)	
	(b) *Uintacrinus* subzone (50 ft.)	
	Zone of *Micraster coranguinum*	200
	Zone of *Micraster cortestudinarium*	100
	Zone of *Holaster planus*	55
TURONIAN	Zone of *Terebratulina lata*	190
	Zone of *Inoceramus labiatus* .. .. .. (including Melbourn Rock at base)	100
CENOMANIAN	Zone of *Holaster subglobosus* .. .. .. (including *Actinocamax plenus* marls at top of zone)	120
	Zone of *Schloenbachia varians* .. .. .. (including Chloritic marl at base of zone)	150
		1330

Special attention is drawn to the exceptional thickness (190 feet) of the *Terebratulina lata* zone, which is maintained throughout the area. The thickness of 150 feet for the *Schloenbachia varians* zone is the same as recorded for the adjoining area in Part I [**4**, p. 358]. The figure of 150 feet for the *Actinocamax quadratus* zone is the thickness in the area of the Downs. No account is taken for any newer Chalk of the zone which may occur in the area of the Coastal Plain between the Downs and the Chichester syncline.

LIST OF PITS AND SECTIONS.

Although this area is largely covered by woodland, it will be noticed that considerable evidence has been secured. Material thrown out by burrowing animals has been of the greatest value, and constitutes a large contribution to the zonal evidence. The whole of the records contained in this list have been zoned by the author. A few of the pits had previously been recorded by the Geological Survey. Reference to the six-inch Sheets of the Ordnance Survey (1914 Edition), on which the evidence is included, is indicated against each item in this list, and each exposure is arranged under the zone in which it occurs, cross references being used when more than one zone is present.

ZONE OF *SCHLOENBACHIA VARIANS*.

Chloritic marl near entrance to field on north side of road, 300 yards W.N.W. of School, Bury. 50 N.W.

Chloritic marl capped by Chalk marl on south side of road in 10 ft. temporary excavation for drainage in grounds of new house. 350 yards west of School, Bury. 50 N.W.

200 ft. O.D. and above, in lane to Westburton Hill, S.W. of West Burton. Top of zone near B.M. 233.9. *Rhynchonella mantelliana*, Sow. *Kingena lima* Defr. 49 N.E.

Small pit on west side of B.R. above 200 ft. O.D., 150 yards N.W. of Old Kiln pit, south of Bignor. *S. varians* Sow. *Nautilus* sp. 49 N.E.

Corner of field by main road on east side of lane to Mill Farm, near spot 187, Duncton. *S. varians*, Sow. Near base of zone. 35 S.E.

Chloritic marl dug for telegraph pole in bank of road at parish boundary, half mile N.E. of St. Giles Church, Graffham. 35 S.W.

Pit at miniature rifle range, 300 yards west of St. Giles Church, Graffham. *S. varians*, Sow. (see *Holaster subglobosus* zone). 35 S.W.

Pit at 300 ft. O.D., north of Gadd's Bottom, Heyshott. 35 S.W.

Top beds of zone 310 to 330 ft. O.D. Bank of track by Old Chalk Pits, Heyshott Down. *S. varians* Sow found at 330 ft. O.D. with *Scaphites* sp. and *Acanthoceras rotomagensis* (d'Orb.). 34 S.E.

Chloritic marl in road bank on south side in area of B.M. 267.5 and spot 268, 200 yards S.W. of Bepton Church. 34 N.E.

Chloritic marl in south bank of road at corner of lane to Linch Down, south of Linch Farm, Bepton. 34 N.W.

Chloritic marl at spot 271, Bugshill Lane, quarter mile S.E. of Manor Farm, Didling. 34 N.W.

Chloritic marl in south bank of road in neighbourhood of spot 207, north of Marfield Pond and quarter mile S.E. of Manor Farm, Treyford. 34 N.W.

Chloritic marl at entrance to field, 100 yards west of B.M. 246.1, south of Redlands, Elsted. 34 N.W.

Pit at 300 ft.—O.D. by B.R. to Beacon Hill, south of Redlands, Elsted. 34 N.W.

Pit N.W. end of Beacon Hill at Casey's Hanger (above 300 ft.O.D.) zoned by the Survey (**8** pp. 66.67). 34 N.W.

Top beds of zone 340-350 ft. O.D. in Telegraph Lane, north of Harting Downs. *Rhynchonella mantelliana* Sow. 33 N.E.

Chloritic marl, road widening bank at West corner of road to Elsted, 200 yards east of Telegraph Lane, East Harting. Marl seen resting on Upper Greensand at about 230 ft. O.D. 33 N.E.

Chloritic marl near 250 ft. O.D. south side of Turkey Island, East Harting. 33 N.E.

Chloritic marl near 250 ft. O.D. in west bank of New Lane, 120 yards east of barn in Tipper Lane, South Harting. 33 N.E.

Roadside pit above 300 ft. O.D. (overgrown) on south side of Hill Lane, Harting. Zoned by the Surrey (**12**, p. 13). 33 N.E.

Bank above road to Castle Farm near 400 ft. O.D. on east side of Hemner Hill, South Harting. *S. varians* Sow. Top beds of zone. 33 N.E.

Chloritic marl at about 240 ft. O.D. in lane bank, 200 yards south of New Barn, west of Hemner Hill, Harting, also in adjoining field by hedge about 150 yards east of last item and at same level, south of B.M. 226.9. 33 N.E.

Chalk pit in field, one-third mile west of Torberry Hill, quarter mile S.W. of Crundell Barn, Harting. *S. varians* Sow. Bottom of 20 S.E.
and Top of 33 N.E.

Roadside pit at N.W. end of Torberry Hill, 100 yards S.W. of Dell Cottage. W.S.W. of Greyhound Inn, Harting. 20 S.E.

ZONE OF *HOLASTER SUBGLOBOSUS*.

Pit reaching just above the 200 ft. contour on west side of main road, quarter mile south of the White Horse Inn, Bury. Belemnite marls exposed in pit capped by Melbourn Rock (see *I. labiatus* zone and **3**, p. 216). 50 N.W.

Base of zone near B.M. 233.9 in bank of lane to Westburton Hill, S.W. of West Burton. 49 N.E.

Pit (Old Kiln) near 350 ft. O.D. by track on escarpment, south of Bignor. 49 N.E.

Road widening between Littleton Farm and the Kennels, Up Waltham, west of Farm Hill. Good sections in east bank seen in 1940 from near spot 422 to near B.M. 414.3. *Ostrea vesicularis*, Lam common near spot 422. Exposure of zone also seen in west bank of main road opposite cottage and garden at Littleton Farm. 35 S.E.

Pit (Old Limekiln) Duncton Hanger, yielding *Holaster trecensis* Leym. Belemnite marls and Melbourn Rock in pit at 400 ft. O.D. (see *I. labiatus* zone) 35 S.E.

Pit at 300 ft. O.D., one-sixth mile S.W. of St. Peter's Church, Lavington Park, East Lavington. Belemnite marls and Melbourn Rock in pit (see *I. labiatus* zone). 35 S.W.

Pit (Old Limekilns) Limekiln Bottom, one-third mile W.S.W. of Graffham Church. *Holaster subglobosus* Leske. Belemnite marls and Melbourn Rock in pit (see *I. labiatus* zone). 35 S.W.

Pit (miniature rifle range) west of St. Giles Church, Graffham (see zone of *Schloenbachia varians*). 35 S.W.

Chalk pit at 400 ft. O.D. in Gadds Bottom, Heyshott. Belemnite marls and Melbourn Rock in pit (see *I. labiatus* zone). 35 S.W.

Pit (Limekiln) by B.M. 366.6, west side of track to summit of Downs, Heyshott Down. 34 S.E.

Actinocamax plenus Blainv. obtained at 440 ft. O.D. in bank of track on east side of old Chalk pits, Heyshott Down. 34 S.E.

Small Pit quarter mile east of Sun Combe, Cocking. 34 S.E.

Pit (Limekilns) reaching 300 ft. O.D., The Butts, on east side of main road, Cocking Hill, Cocking. 34 S.E.

Railway section by north entrance to Cocking tunnel. 34 S.E.

Pit at about 400 ft. O.D., south of St. Andrew's Church, Didling. 34 N.W.

Bank of track to Didling Hill, with small pit above 400 ft. O.D. 34 N.W.

Small pit by track, half mile S. W. of Treyford. 34 N.W.

Small pits on south side of Hill Lane, Harting, reaching 400 ft. O.D. 33 N.E.

Pits between 300 ft. and 400 ft. O.D. on west side of main road, Harting Hill, north of Tower in Up Park. Junction of Belemnite marls and Melbourn Rock at 400 ft. O.D. (See *I. labiatus* zone). 33 N.E.

Bank of road to Castle Farm and two pits on west side between 400 ft. O.D. on east side of Hemner Hill, Harting, and Forty Acre Lane, also banks of road between Forty Acre Lane and Castle Farm, Harting. 33 N.E.

ZONE OF *INOCERAMUS LABIATUS*.

Pit reaching just above the 200 ft. contour on west side of main road, quarter mile south of the White Horse Inn, Bury, Melbourn Rock in top of pit at south end. (See *H. subglobosus* zone and **3**, p. 216). 50 N.W.

Base of Melbourn Rock at about 460 ft. O.D. in bank of track on West side of Westburton Hill, half-mile S.W. of West Burton. 49 N.E.

Base of Melbourn Rock in banks of tracks at 365 ft. O.D. S.W. and S.E. of Old Kiln, half mile south of Bignor, also small pit at 400 ft. O.D. by track S.E. of Old Kiln, yielding *I. labiatus* (Schloth.). 49 N.E.

Pit at 400 ft. O.D. south of Coldharbour Farm, S.W. of Bignor. *Terebratulina striata*. Wahl. from Melbourn Rock at entrance to pit, *Rhynchonella cuvieri*, d'Orb. in pit's face. *I. labiatus* (Schloth.) common. 49 N.E.

Base of Melbourn Rock at top of Puck Street, Sutton, at 500 ft. O.D. 49 N.E.

Base of Melbourn Rock at 465 ft. O.D., exposed in Arundel Lane, north of Littleton End, Barlavington. *Labiatus* rock exposed in bank of lane at 500 ft. O.D. 49 N.E.

Pit (Old Limekiln) Duncton Hanger. Melbourn Rock in top of pit at 400 ft. O.D. (See *H. subglobosus* zone). 35 S.E.

Pit above 450 ft. O.D., 150 yards north of Kennels, S.W. of Barlavington Down. Hard nodular chalk, yielding *I. labiatus* (Schloth.). 35 S.E.

Chalk in bank of track between 400 and 500 ft. O.D. on south side of Northcomb Wood, five-sixths mile S.W. of St. John's Church, Sutton—base of Melbourn Rock at 385 ft. O.D. 35 S.E.

Chalk pit by main road on west side of Duncton Down above 400 ft. O.D. *I. labiatus* common near entrance to pit on east side. Chalk with nodules and *I. labiatus* at bottom of pit at south end. 35 S.E.

Bank of track at Littleton Farm to Littleton Down, Duncton—400-450 ft. O.D., yielding *Inoceramus labiatus*, Schloth. 35 S.W.

Rhynchonella cuvieri. d'Orb., and small *Ostrea vesicularis*, Lam. in pit above 500 ft. O.D., quarter mile N.W. of Littleton Farm, Duncton. 35 S.W.

Labiatus Rock in bank of path to Church near Church Farm, Up Waltham. 49 N.W.

Melbourn Rock at 400 ft. O.D. in top of pit (Old Limekilns) Limekiln Bottom, one-third mile W.S.W. of Graffham Church. (See *Holaster subglobosus* zone.) 35 S.W.

Chalk pit at 400 ft. O.D. in Gadd's Bottom, Heyshott. 5 feet of Melbourn Rock exposed in top of pit. (See *H. subglobosus* zone.) 35 S.W.

Pit at 300 ft. O.D. one-sixth mile S.W. of St. Peter's Church, Lavington Park, East Lavington—upper part of pit . (See *H. subglobosus* zone.) 35 S.W.

Base of Melbourn Rock at 445 ft. O.D. in back of track east of old Chalk pits, Heyshott Down. 34 S.E.

Pit above 400 ft. O.D. on east side of Sun Combe, Cocking. Large *Terebratula* with *Rhynchonella cuvieri* d'Orb. from centre of pit. (See *Terebratulina lata* zone.) 34 S.E.

West bank of main road, above 200 ft. O.D. west of Singleton Rectory. Hard Chalk with abundance *I. labiatus* in lower part of section. Also west bank of Town Lane on east side of West Dean Park, about quarter mile S.W. of Singleton Church, above 200 ft. O.D. Hard Chalk with *I. labiatus*, Schloth. These exposures form part of the inlier of Chalk of the *I. labiatus* zone at Singleton on the axis of the Singleton anticline. 48 N.E.

Flat above 400 ft. O.D. and in bank of track at Bepton at east end of Bepton Down. 34 N.E.

Melbourn Rock at about 470 ft. O.D. in bank of track from Linch Farm to Linch Down, Bepton. 34 N.W.

Base of Melbourn Rock at 465 ft. O.D. in bank of track from Didling to Didling Hill. 34 N.W.

Pit (Old Limekiln) above 500 ft. O.D. on east side of track from Didling to Didling Hill. 34 N.W.

Base of Melbourn Rock at 460 ft. O.D. in bank of track from Treyford to Buriton Farm. 34 N.W.

Pit at 475 ft. O.D. on south side of track from Treyford to Buriton Farm. 34 N.W.

Base of Melbourn Rock in track above small pit near 450 ft. O.D., south of spring, south of Elsted Hanger. 34 N.W.

Melbourn Rock at 500 ft. O.D. in bank of track from Elsted to Beacon Hill on east side of Hump Back Plantation. 34 N.W.

At about 520 ft. O.D. bank of F.P., south of Mount Sinai, north of earthwork on Pen Hill, Elsted. Hard Chalk yielding fragments of *I. labiatus* and *Rhynchonella cuvieri*, d'Orb. 34 N.W.

Melbourn Rock at about 430 ft. O.D., south of Casey's Copse, in bank of Telegraph Lane, south of East Harting. 33 N.E.

Melbourn Rock above 400 ft. O.D. in road bank by Downs Place, Hill Lane, Harting. 33 N.E.

Base of Melbourn Rock at 400 ft. O.D. in road bank by pits on west side of main road to Chichester, Tower Hill, South Harting. Pit with abundant *Inoceramus labiatus* immediately above. 33 N.E.

Melbourn Rock 500 ft. and above. Hemner Hill, three-quarter mile west of St. Mary's Church, South Harting. Outlier of zone. 33 N.E.

Labiatus Rock in road bank on south side of Castle Farm, Harting, at foot of east side of West Harting Down. 33 N.E.

ZONE OF *TEREBRATULINA LATA*.

Quarry on Bury Hill on west side of main road, half mile south of White Horse Inn, Bury, near the 300 ft. contour (see **3** p. 216). 50 N.W.

Small pit above 600 ft. O.D., S.W. of larger pit, east of Scotcher's Bottom, two-thirds mile W.S.W. of Glatting Farm, Sutton. 49 N.E.

Large pit above 600 ft. O.D. (referred to in last item), Denture, S.W. of Springs, Glatting Hanger, Sutton—low in zone. 49 N.E.

Large overgrown pit above 600 ft. O.D. west of Scotcher's Bottom, Littleton End, Sutton. 49 N.E.

Pit on Duncton Down, above 600 ft. O.D. west of tumulus. *T. lata*, Eth. common. Few flints. 35 S.E.

Pit 100 yards east of Hazel Comb, Farm Hill, one mile S.W. of Sutton. 35 S.E.

Chalk of zone exposed on summit of Farm Hill at 700 ft. O.D., one mile S.W. of Sutton, also *T. lata* Eth. obtained at 600 ft. O.D., on south side of Farm Hill. 35 S.E.

T. lata Eth. obtained in bank of B.R. at 560 ft. O.D. east of south end of large pit on Woolavington Down, East Lavington. Top of zone. 35 S.E.

Bank of B.R., N.W. of Littleton Farm, East Lavington, between 525-550 ft. O.D. 35 S.W.

Pit, 200 yards east of Droke Cottage, Up Waltham, at 400 ft. O.D. Upper beds of zone. Nodular flints. 49 N.W.

Chalk pit above 500 ft. O.D., 400 yards N.W. of Up Waltham Church, *T. lata* Eth. obtained. 49 N.W.

Old Limekiln pit near 300 ft. O.D., south of Manor Farm, East Dean. 48 N.E.

Two small pits above 300 ft. O.D., Chalk Road, south of Charlton, Singleton. 48 N.E.

Chalk pit on east side of Town Lane, Singleton, near 300 ft. O.D. 48 N.E.

Railway section on north side of bridge by Chitty's Plantation. Hat Hill, Singleton. *T. lata* Eth. obtained 100 yards north of bridge. 48 N.E.

Chalk Pit on north side of lane near B.M. 274.4, quarter mile west of Singleton Railway Station. 48 N.E.

Railway sections at North and south ends of Westdean tunnel. 48 N.E.

Railway sections on north and south side of bridge over main road by West Dean Farm, south of School, West Dean. Top beds of zone on south side of bridge. 48 N.E.

Pit above 400 ft. O.D. on east side of Sun Combe, Cocking. Junction with zone of *I. labiatus* in centre of pit. (See *I. labiatus* zone.) 34 S.E.

Pit near B.M. 454 ft. on north side of Hillbarn Lane, East of Hill Barn, Cocking. 34 S.E.

Small Chalk pit near B.M. 465.7, west end of Middlefield Lane, Cocking Down, Cocking. 3 ft. of nodular Chalk in centre of pit. 34 S.E.

Pit near 550 ft. O.D. on west side of Treyford Hill, one-sixth mile S.E. of Buriton Farm. 34 N.W.

JUNCTION OF *TEREBRATULINA LATA* AND *HOLASTER PLANUS* ZONES.

The following evidence contains the junction of the *Terebratulina lata* and *Holaster planus* zones :—

Small pit, south of Glatting Hanger and Pitchurst Copse, near 700 ft. O.D. and words " Burton (Det. No. 4)." Junction of *T. lata* and *H. planus* zones immediately above top of pit. 49 N.E.

Pit at about 650 ft. O.D., east of triangulation spot 684 on Barlavington Down, south of Duncton Hanger. Index fossil common in Chalk at top of *T. lata* zone. Junction of *T. lata* and *H. planus* zones in top of pit. 35 S.E.

Large pit on Woolavington Down, south of Lavington Park, East Lavington. Exposure above talus in *Holaster planus* zone yielded Micrasters, including *Micraster* *cortestudinarium* (Goldf.), also *Pleurotomaria perspectiva* (Mant.), *Rhynchonella cuvieri* d'Orb. Lower part of pit in *T. lata* zone. 35 S.E.

Old Chalk pits, Heyshott Down. *T. lata* at 625 ft. O.D. Upper part of pit above this yielded small Micrasters of *Holaster planus* zone. 34 S.E.

Roadside section at about 360 ft. O.D., 100 yards south of Old Limekiln pit, one-sixth mile south of Manor Farm, East Dean. *T. lata* zone with base of *H. planus* zone in top of section. 48 N.E.

Small pit just below 300 ft. O.D. on east side of North Lane, North Down, east of Levin Down, Singleton, north of spot 271 at top of Sheet 48 N.E. Top beds of *T. lata* zone. *T. lata* common. In bank east of spot 271. base of *Holaster planus* zone at 300 ft. O.D. 48 N.E.

Old pit, south of Sun Combe, west end of Manor Farm Down, Cocking. Junction of *T. lata* and *H. planus* zones seen near 600 ft. O.D. at top of north end of pit. 34 S.E.

Overgrown pit above 600 ft. O.D., top of Hill Lane, near junction of South Harting-Chichester road, west end of Harting Downs. Junction of *T. lata* and *H. planus* zones ascertained at east end of pit. 33 N.E.

Junction of *T. lata* and *H. planus* zones.

Near 575 ft. O.D., west of triangulation spot on Westburton Hill, half mile south of West Burton. 49 N.E.
450 ft. O.D., quarter mile east of King's Buildings, south of Westburton Hill. 49 N.E.
500 ft. O.D. 20 feet below track, about 200 yards north of King's Buildings, half mile S.E. of Bignor Hill. 49 N.E.
640 ft. O. D. east side of Bignor Hill. 49 N.E.
650 ft. O.D.—10 ft. below B.R., 150 yards S.S.W. of triangulation spot 684, Littleton end, also 10 ft. above S.W. end of supposed Intrenchment (below 650 ft. O.D.), 300 yards south of triangulation spot 684. Littleton End, Sutton. 49 N.E.
At about 530 ft. O.D. in Lavington Lane, one-third mile W.S.W. of St. Peter's Church, East Lavington. 35 S.W.
645 ft. O.D., Littleton Down, N.W. of Littleton Farm, East Lavington. 35 S.W.
About 450 ft. O.D. N.W. of Lower Barn, Up Waltham. 49 N.W.
At 500 ft. O.D., east of pit and 300 yards east of Droke Cottage, Up Waltham. 49 N.W.
Near 430 ft. O.D. by White Road, north of Droke, East Dean. 49 N.W.
At about 420 ft. O.D. by F.P. above Courthill Lane, 300 yards north of East Dean Church. 49 N.W.
About 360 ft. O.D., west bank of Chalk Road, Charlton, Singleton. 48 N.E.
On Levin Down, just above 400 ft. O.D., 200 yards east of gate in lane to Levin Down, quarter mile north of west end of Bankfield Cottages, Singleton. 48 N.E.
Road bank at 350 ft. O.D. on west side of Town Lane, Singleton. 48 N.E.
Railway section 725 ft. south of Drove tunnel, one-sixth mile N.W. of Cucumber's Farm, Singleton. (See Zone of *Micraster cortestudinarium*.) 48 N.E.
North bank of lane by track, just below B.M. 322.9 at Crouches Bank, quarter mile N.W. of Singleton Railway Station. 48 N.E.
About 690 ft. O.D. Cart track on Bepton Down. 34 N.E.
At 700 ft. O.D. Pen Hill, south of Elsted. 34 N.W.
At 580 ft. O.D. on hill quarter mile W.S.W. of Buriton Farm, and south of Pen Hill, Elsted. Summit of hill about 590 ft. O.D. 34 N.W.
At 650 ft. O.D., east bank of track. 150 yards S.W. of British Camp on Beacon Hill, Harting Downs. 33 N.E.
North end of 700 ft. contour. Round Down. Harting Downs. 33 N.E.
700 ft. O.D., north of triangulation spot 708, West Harting Down. 33 N.E.

ZONE OF *HOLASTER PLANUS*.

(Junction of *T. lata* and *H. planus* zones. See evidence immediately above)

Bank of B.R. between 580 and 625 ft. O.D., south of Coldharbour Farm, one mile S.W. of Bignor. *Holaster planus*, Mant., *Micraster corbovis*, Forbes and *M. praecursor*, Rowe. 49 N.E.

Pit, east of B.M. 453.7, south of Droke Cottage, Up Waltham. *Micraster praecursor*, Rowe. *Pleurotomaria perspectiva* (Mant.). 49 N.W.

Rut in New Road, East Dean, just below 400 ft. O.D., 350 yards N.E. of New Barn. *Micraster praecursor* Rowe. *Rhynchonella plicatilis* (J. Sow.) 49 N.W.

Chalk dug for Pylon (Electricity) at parish boundary, about 100 yards N.N.W. of Chitty's Plantation, west of railway, Hat Hill, Singleton. Hard nodular Chalk. *Micraster praecursor* Rowe, *Holaster placenta*, Agas. 48 N.E.

Small pit at B.M. 255.6 on south side of lane to Warren Down, south of Whitedown Plantation, quarter mile N.W. of School, West Dean. *Holaster planus*, Mant. 48 N.W.

North bank of Hillbarn Lane at about 525 ft. O.D., east of B.M. 495.3, Manor farm Down, Cocking. *Micraster corbovis* Forbes *Rhynchonella cuvieri* d'Orb. 34 S.E.

700 ft. O.D. and just above, Linch Down, one-sixth mile W.N.W. of Linch Ball, Bepton. *Holaster planus* Mant. 34 N.W.

At 700 ft. O.D., 100 yards W.N.W. of tumulus, Didling Hill, south of St. Andrew's Church, Didling. Small Micrasters. 34 N.W.

N.E. end of 700 ft. O.D. Harting Hill, Harting Downs. 33 N.E.

ZONE OF *MICRASTER CORTESTUDINARIUM.*

About 600 ft. O.D. in Lavington Lane, half mile W.S.W. of St. Peter's Church, East Lavington. *Micraster cortestudinarium* (Goldf.), *M. praecursor* Rowe. *Lima hoperi* Mant. *Serpula fluctuata* J. de C. Sow. 35 S.W.

Micrasters of zone obtained in bank of cart track above Gadd's Bottom, Heyshott, between 665 and 690 ft. O.D. 35 S.W.

Pit by hedge on south side of Newhouse Lane, 150 yards N.E. of Pond Barn, East Dean. S.W. end of 35 S.W.

Chalk dug for Pylon (Electricity) at about 500 ft. O.D. on south side of Hat Hill, Singleton, quarter mile west of railway. Upper beds of zone. 48 N.E.

Near 400 ft. O.D. In field or east side of B.R. to "Canada," west of Withy bed and Chills Down, West Dean. *Micraster praecursor* Rowe and *Echinocorys scutatus* Leske. 48 N.E.

Railway section at south entrance to Drove tunnel, Singleton to 440 ft. southward from tunnel where Chalk showing junction of *Micraster cortestudinarium* and *Holaster planus* is exposed and 725 ft. from tunnel junction of *Terebratulina lata* and *Holaster planus* zones is seen. End of section in *Terebratulina lata* zone at 875 feet south of tunnel. Dip north. 34 S.E. and 48 N.E.

Pit above 300 ft. O.D. on east side of main road at Wolverstone Farm (Old Limekilns), half mile south of Cocking Hill. *Micraster praecursor* Rowe, *Echinocorys scutatus* Leske (small). 34 S.E.

Railway section about 750 ft. in length north and south of bridge over railway, west of Wolverstone Farm, half mile south of Cocking Tunnel. 34 S.E.

700-710 ft. O.D. on summit of Downs where track south of Linch Farm, Bepton, joins track along summit of Downs at west end of Linch Down by parish boundary, near B.M. 698.3. *Ventriculites radiatus* Mant., *Echinocorys scutatus* Leske (small). 34 N.W.

Roadside section on east side, N.W. of Dell Bridge Plantation (about 370 ft. O.D.) North Marden. *Micraster praecursor* Rowe, *Echinocorys scutatus* Leske, with encrusting Polyzoa typical of zone. 33 S.E.

Small pit in field on south side of road, south of Dell Bridge Plantation (below 400 ft. O.D.) North Marden. 33 S.E.

Pit by roadside near B.M. 470.5 at south end of Booker Down, S.E. end of West Harting Down. *Micraster praecursor* Rowe. Small specimens of *Echinocorys scutatus* Leske common. Low in zone. 33 N.E.

ZONE OF *MICRASTER CORANGUINUM.*

Trochiliopora bed, summit of Downs, half mile south of Coldharbour Farm between 700 ft. O.D. and tumuli, east of Stane Street, S.W. of Bignor Hill, Bignor. 49 N.E.

Trochiliopora bed between tracks above 700 ft. O.D. on Burton Down about 200 yards west of triangulation spot on Glatting Beacon (site of) and about 200 yards south of supposed Intrenchment, Burton (Det. No. 4). 49 N.E.

Basement beds of zone N.E. end of supposed Intrenchment above 700 ft. O.D., south of Littleton End, Sutton Down. 49 N.E.

Trochiliopora gasteri, Thomas obtained at 530 ft. O.D. on west side of Up Waltham Hill, three-quarter mile south of Up Waltham Church. 49 N.W.

Basement beds of zone in neighbourhood of triangulation spot 556, on High Down, East Dean. 49 N.W.

Basement beds of zone in neighbourhood of F.P. on High Down, East Dean, for about one-third mile from B.M. 551.3 in a N.E. direction to top of sheet. *Pharetrospongia strahani*, Sollas. *Serpula ilium*, Goldf. 49 N.W.

Near 500 ft. O.D. on south side of Selhurstpark Road, 200 yards east of Pilleygreen Lodges, Eastdean Hill. *Conulus* sp. Top beds of zone. 49 N.W.

Basement beds of zone above 800 ft. O.D., south of triangulation spot 837. Crown Tegleaze, west of Littleton Down, East Lavington. 35 S.W.

Basement beds of zone from parish boundary near B.M. 721.7 to parish boundary near 774.1 in banks of New Road, north of Waltham Down, Up Waltham. 35 S.W.

Trochiliopora bed at tumuli and B.M. 679.3 on south side of New Road, East Dean, west of Waltham Down. 35 S.W.

Basement beds of zone at about 770 ft. O.D. by cross tracks, 200 yards west of Intrenchment, quarter mile west of Bishops Ring, Woolavington Down, East Lavington. 35 S.W.

Trochiliopora bed, south of tumulus near spot 689 ft. Graffham Down. 35 S.W.

Trochiliopora bed above 700 ft. O.D., 250 yards east of parish boundary, half mile south of Hayland Farm, Graffham. 35 S.W.

Trochilopora bed above 700 ft. O.D., 200 yards east of spot 730 ft. and 350 yards S.S.W. of cottage in Gadd's Bottom, Heyshott. 35 S.W.

Fragments of *Inoceramus* sp. common in Chalk, 25 yards south of S.E. end of Shepherd's Croft, 100 yards south of New Road, East Dean. 35 S.W.

Pit on south side of Limekiln Bottom, one-third mile east of shooting Pond, East Dean. 35 S.W.

Trochiliopora bed, flat above 400 ft. O.D., 450 yards E.N.E. of Pond Barn, south of Newhouse Lane, East Dean. 35 S.W.

Bank on south side of Newhouse Lane, 200 yards west of Postles Barn, East Dean, near 350 ft. O.D. *Homoeosolen* sp. Fragments of *Inoceramus* sp. common. 35 S.W.

Trochiliopora bed, 200 yards east of Intrenchments at about 750 ft. O.D., Heyshott Down. *Actinopora* sp., *Clausa globulosa* d'Orb. 34 S.E.

Basement beds of zone above 700 ft. O.D., 500 ft. west of Intrenchments and westward for 500 yards on north side of parish boundary, Heyshott Down, where it joins Manor farm Down. *Trochiliopora gasteri* Thomas obtained 100 ft. north of parish boundary at east end of evidence. 34 S.E.

Chalk pit at 400 ft. O.D., Yorkhurst Hill, one-third mile S.E. of Broadham Cottages, south of Singleton Forest, Singleton. *Micraster coranguinum* Leske 34 S.E.

Basement beds of zone, North Down, about 25 ft. above North Lane on south side, 100 yards S.W. of B.M. 331.7, quarter mile S.W. of Forest House, Singleton. *Pharetrospongia strahani* Sollas. Polyzoa. 34 S.E.

Basement beds of zone at 400 ft. O.D., one-third mile E.S.E. of Drove House, south of east end of Garden Copse, Singleton. 34 S.E.

Pit on east side of main road, 150 yards S.S.E. of Littlewood Farm, south end of Littlewood Common, Singleton. Basement beds of zone. *Micraster praecursor* Rowe, *Pharetrospongia strahani* Sollas. 34 S.E.

Railway section on north side of Drove tunnel—400 ft. in length—south of Littlewood Farm, Singleton. Strong tabular flint seam in section about level with top of tunnel. Chalk practically horizontal in centre. 34 S.E.

NOTE. These last two items constitute the evidence of the Littlewood Syncline already referred to at this spot.

Above 600 ft. O.D., west side of parish boundary at north end of Court Hill Plantation, Singleton. Basement beds of zone. Fragments of *Inoceramus* sp. common. 48 N.E.

Flat outside of west end of Court Hill Plantation, Singleton, near triangulation spot 585. Basement beds of zone. *Pharetrospongia strahani* Sollas. 48 N.E.

Trochiliopora bed, middle of Levin Down Clump on north side, Levin Down, Singleton. 48 N.E.

Pit about 450 ft. O.D., north of Goodwood Racecourse and Grand Stand, Charlton Down, Singleton. 48 N.E.

Pit by track at east end of Calhouns Plantation, south of West Dean Park. 48 N.E.

Chalk pit just above 200 ft. O.D. at west end of Haye's Down, Binderton, east of railway, one mile south of West Dean. *Micraster coranguinum* Leske, *Bourgueticrinus* (barrel shaped) *Mitraster rugatus* Forbes. 48 N.E.

Pylon (Electricity) between N.W. corner of copse at " Canada " and 500 ft. O.D., half mile N.N.W. of Singleton railway station. *Echinocorys scutatus* Leske (large) with specimens of *Thecidium wetherelli* Morris encrusting. Fragments of *Inoceramus* sp. common. 48 N.E.

Pit above 400 ft. O.D., one-eighth mile east of Heath Barn, south end of Heathbarn Down, West Dean. *Micraster coranguinum* Leske. 48 N.W.

Pit, 150 yards S.S.W. of Warren Barn, and pit 150 yards S.E. of Warren Barn, S.W. of Warren Down, West Dean. 48 N.W.

Pit in Binderton Lane, East of Laurence Copse, Binderton. 48 N.W.

Pit at Welldown Farm, Lavant, near B.M. 172.8. Strong tabular flint seam in centre of pit. 48 S.W.

Trochiliopora bed at 800 ft. O.D., Linch Ball, Linch Down, Bepton. 34 N.W.

Roadside pit near B.M. 354.9 west side of Stapleash Down, quarter mile S.E. of Stapleash Farm, West Dean. *Conulus* belt. 34 S.W.

Roadside section on east side, above 400 ft. O.D., south of North Marden Down and Dell Bridge Plantation, North Marden. Basement beds of zone. *Micraster* *cortestudinarium* (Goldf.), *M. praecursor* Rowe. *Trochiliopora gasteri* Thomas obtained from bank at top of section. 33 S.E.

Trochiliopora bed by footpaths in field, 100 yards east of Up Park Lodge at North Marden Gate, North Marden. 33 S.E.

Chalk pit at Chalkpit Plantation, ¾ mile N.E. of Compton Church. 33 S.E.

Pit at Cowdown Barn (by pond) Cowdown Lane, W.N.W. of Compton. 33 S.E.

ZONE OF MARSUPITES TESTUDINARIUS

UINTACRINUS SUBZONE.

Chalk dug for fence by gardens of cottages on north side of road, west of B.M. 234.7, one-third mile N.E. of Madehurst Church. 49 S.E.

Road bank on south side, just below Reservoir and east of footpath, quarter mile N.N.E. of Madehurst Church. 49 S.E.

300 ft. O.D. between Dale Park and S. end of Ashlee Wood, Gt. Down, Slindon. 49 S.E.

Above 400 ft. O.D. west of N. end of Ashlee Wood, Gt Down, Slindon. 49 N.E.

500 ft. O.D. and above, between west end of Stammers Wood and parish boundary, Madehurst. 550 yards W.N.W. of Stammers. 49 N.E.

Flat above 500 ft. O.D., W. of parish boundary, Gt. Down, Slindon. Upper part of subzone to base of *Marsupites* subzone at S. end of 500 ft. contour and just below. 49 N.E.

Roadside pit on west side of Chichester to Petworth road at 300 ft. O.D. and parish boundary, S.E. of Selhurstpark Farm and three-quarter mile N.N.W. of George Inn, Eartham. 49 S.W.

In wood on west side of Chichester to Petworth road, 200 yards south of junction with Eartham road, Up Waltham, 200 yards north of pit last described. 49 S.W.

Pit, 100 yds. W. of Middle Barn, ⅓rd mile S. of Selhurstpark Farm, East Dean. 49 S.W.

About 560 ft. O.D. track on north side of Selhurstpark road, north of spot 569, south of Potcomb, East Dean. 49 N.W.

At about 460 ft. O.D. on east side of Halnaker Gallop, S.E. of Eastdean Hill, East Dean. 49 N.W.

Between west end of Stonehill Clump and footpath, 300 yards S.E. of Counter's Gate, south of Eastdean Park, East Dean. 48 N.E.

100 ft. south of S. end of Stonehill Clump, S. of Eastdean Park, East Dean. 48 N.E.

Just above 400 ft. O.D., 100 ft, east and 100 ft. S.E. of spot 432, east of road and Molecomb Peak, East Dean. Top N.E. corner of 48 S.E.

At about 350 ft. O.D., north of parish boundary, east of road, quarter mile east of north end of Soldier's Clump, East Dean. 48 S.E.

Bottom of shallow pit above 500 ft. O.D. at west end of The Plantation, 200 yards south of Goodwood Racecourse (quarter mile east of Grand Stand), Singleton. (See Marsupites subzone.) 48 N.E.

Track at N.W. end of The Trundle, Singleton, 400 yards N.W. of triangulation spot with B.M. 678, one-third mile N.W. of Seven Points Cottages. 48 N.E.

About 450 ft. O.D. at north end of valley at S.W. end of St. Roche's Hill on east side of road, 150 yards S.E. of Seven Points Cottages, Lavant. 48 N.E.

Temporary E—W excavations at about 410 ft. O.D., also at 350-360 ft. O.D. centre of flat, Lavant Down, Lavant. 48 S.E.

At 462 ft. O.D. 50 yards south of B.M. 437.1 at east end of Calhouns Plantation, also 450, 422 and 410 ft. O.D. south of Calhouns Plantation, Haye's Down, Lavant. 48 N.E.

Temporary E—W excavations at about 350-370 ft. O.D., west of road at east end of Haye's Down, Lavant. 48 S.E.

Temporary E—W excavations at about 315-345 ft. O.D., west of road near B.M. 343 at east end of Haye's Down, Lavant. Lower part in *Uintacrinus* subzone, upper part in *Marsupites* subzone. 48 S.E.

350, 310, 275, 265, 255 ft. O.D. In Kingley Vale at and on east side of parish boundary, Stoughton, at intervals from parish boundary at bottom of Sheet 48 N.W. southward for 700 yards. 48 N.W. 48 S.W.

Just below 350 ft. O.D. on east side of B.R., half mile S.E. of Bow Hill and two-thirds mile west of Welldown Farm, Lavant. 48 S.W.

By boundary stone at 400 ft. O.D., S.E. of Bow Hill and three-quarters mile west of Memorial Cottages, Binderton. 48 N.W.

Chalk around overgrown pit just above 300 ft. O.D. in field 200 yards west of Hylters's Lane, one-third mile N.W. of Warren Barn, West Dean. 48 N.W.

Chalk pit on north side of Hylters, Hylters's Lane, West Dean. 48 N.W.

Stapleash Down, West Dean. Base of subzone by F.P. at north end of 400 ft. contour. Upper part of subzone at 400 ft. O.D., one-sixth mile S.W. from base. 34 S.W.

Lower workings of pits on south side of road, south of White Horse Inn, Chilgrove, West Dean—below 300 ft. O.D. 34 S.W.

320 ft. O.D. south side of Philliswood Lane, between Oakwood Copse and main road, five-sixths miles east of East Marden village. 34 S.W.

380 ft. O.D. B.R. at parish boundary, 200 yards east of Hill Land Corner, also 150 yards southward at same level, two-thirds mile E.N.E. of East Marden church. 34 S.W.

Road bank on north side, 400 yards east of East Marden church 34 S.W.

On south side of road at north end of Apple Down, 50 yards west of B.M. 447.9, one-sixth mile east of Fernbeds Farm, Up Marden, also in field on south side of road near spot 410, quarter mile west of Fernbeds Farm, also in same field 120 yards S.E. of Chalkpit Plantation. 33 S.E.

Bank of lane, 50 yards south of Compton Church, just west of footpath to church. 33 S.E.

Roadbank on east side near B.M. 354.6 Compton Down. 33 S.E.

Cowdown Lane, Compton, 100 feet west of spot 354. 33 S.E.

HAMPSHIRE. 320 ft. O.D., 70 yards east of old Chalk pit and at intervals for about 400 yards eastward in banks of Huckswood Lane, Idsworth. 68 N.E.

About 360 ft. O.D., 70 yards south of road, Chalton Peak, 400 yards east of Chalton Church. 68 N.E.

MARSUPITES SUBZONE.

Road bank in Arundel Park, 80 yards S.E. of Whiteways Lodge, Houghton. Smooth plate. 50 S.W.

Just below 300 ft. O.D., 150 yards south of Ashlee Wood, Slindon, West of parish boundary by Dale Park. Ornate plates. 50 S.E.

Parish boundary at about 320 ft. O.D., The Plain, one mile N.E. of Eartham Church. Ornate plates. 49 S.W.

Pit by Stane Street at 300 ft. O.D. at S.W. end of Copythorn Plantation, half-mile. N.N.W. of George Inn, Eartham. *Terebratulina rowei*, Kitch. 49 S.W.

Near 300 ft. O.D., 300 yards east of road, Hat Hill, five-sixths mile north of Halnaker House (remains of), Boxgrove. Ornate plates. 49 S.W.

Shallow pit about 500 ft. O.D. at west end of The Plantation, 200 yards south of Goodwood Racecourse (quarter mile east of Grand Stand), Singleton. Smooth plates. (See *Uintacrinus* subzone.) 48 N.E.

Road bank at east corner, near spot 525, south of Goodwood Racecourse (400 ft. east of Grand Stand), Singleton. Smooth plates. *Terebratulina rowei* Kitch. 48 N.E.

Just below 600 ft. O.D. on north side of The Trundle, one-third mile N.W. of Grand Stand at Goodwood Racecourse, Singleton. Ornate plate. 48 N.E.

West bank of road, southward for 300 yards from Seven Points Cottages, Haye's Down, Lavant. Smooth plates. 48 N.E., 48 S.E.

Temporary E—W excavations at about 315-345 ft. O.D., west of road near B.M. 343.0 at east end of Haye's Down, Lavant. Smooth plates in upper part. (See *Uintacrinus* subzone). 48 S.E.

Temporary E—W excavations, west of Camp at Bexley Bushes, south side of west curve of earthwork, Lavant Down, Lavant, near 225 ft. O.D. Smooth plates. 48 S.E.

East bank of road at 325 ft. O.D. on west side of Goodwood Park between Kennel Slip and Target Bottom, Lavant, south of B.M. 349.0. Ornate plates. 48 S.E.

Pit 300 ft. O.D. at parish boundary, quarter mile N.N.E. of Goosehill Camp, 500 yards N.W. of Brickkiln Farm, Binderton. Ornate plates. 48 N.W.

450 ft. O.D. by track, N.W. from Dean Cottages, Binderton. 48 N.W.

Flat, 100 yards N.E. of pond by spot 315, threequarter mile W.S.W. of Welldown Farm, Lavant. Ossicles. 48 S.W.

Shallow pit at 400 ft. O.D., quarter mile east of parish boundary in Kingley Vale, nearly one mile west of Welldown Farm, Lavant. Ornate plates. 48 S.W.

Near 350 ft. O.D. north-west of N.W. earthwork and tumuli Bow Hill, Stoughton. Ornate plates. Ossicles and *Kingena lima* (Defr.) between 350 and 400 ft. O.D. 48 N.W.

Upper workings of pits, above 300 ft. O.D., south of White Horse Inn, Chilgrove, West Dean. Ornate plates. *Actinocamax granulatus* (de Blainv.) See *Uintacrinus* subzone. 34 S.W.

Roadside section by B.M. 418.5, one-sixth mile north of Corner Clump, East Marden Down. Ornate plates at 405 ft. O.D. *Terebratulina rowei* Kitch. 34 S.W.

Above 400 ft. O.D., Apple Down, one-sixth mile S.S.E. of Fernbeds Farm, Up Marden. 33 S.E.

Lane bank at East Hanger, above 300 ft. O.D., 120 yards S.E. of Compton Church. Ornate plates. 33 S.E.

North End of 400 ft. contour, Compton Down. Ornate plates. 33 S.E.

HAMPSHIRE. Old Chalk pit, Idsworth Farm, Idsworth. Ossicles. 68 N.E.

ZONE OF *OFFASTER PILULA*.

Offaster pilula, Lam., in Chalk from uprooted tree in Arundel Park, at south end of Park Rough (above 400 ft. O.D.), 640 yards S.S.E. of Whiteways Lodge, Houghton. 50 S.W.

Serpula ilium Sow. (large) at about 350 ft. O.D. at north end of Nore Hill, N.E. of Eartham Village. 49 S.W.

Chalk yielding *Offaster pilula* Lam. at 385 ft. O.D., 250 yards north of Halnaker Windmill, Boxgrove. Top beds of zone. 49 S.W.

At about 330 ft. O.D., 500 yards north of Halnaker Windmill, Boxgrove. *Offaster pilula* Lam., *Terebratulina rowei*, Kitch., *Serpula ilium* Sow. (large) 49 S.W.

Above 600 ft. O.D. below The Trundle, British Camp, at S.E. end, S.E. of B.M. 678, west of Goodwood Racecourse, Singleton. *Offaster pilula* Lam., *Serpula ilium*, Sow. (large). 48 N.E.

Chalk pit on east side of Chalk pit Lane, adjoining Chalkpit Plantation,Lavant. Belt of *Echinocorys scutatus* var. *truncata* in pit. Chalk also yielding *Offaster pilula* Lam. and *Serpula ilium* Sow. (large). 48 S.E.

Pit, south side of road, 100 yards east of Forage Yard, east of Middlefield Lane, Lavant. *Hagenowia* horizon. 48 S.E.

Chalk pit, 200 yards north of Trumley Copse, Lavant. N.W. face of pit above talus yielded small *Echincorys* including *E. scutatus* var. *cincta* Brydone, also *Actinocamax granulatus* (de Blainv.) *Hagenowia* horizon. (See *A. quadratus* zone.) 48 S.W.

Pit workings with Phosphatic Chalk, quarter mile north of Stoke Clump and three-quarter mile west of Langford Farm, Lavant. Fish teeth (abundant) *Serpula ilium* Sow (large), *Offaster pilula* Lam., *Ostrea canaliculata* J. Sow. (var. *striata*), *Terebratulina rowei* Kitch. About middle of zone. 48 S.W.

Woodend pit, Funtington. *Ostrea canaliculata* J. Sow. (var. *striata*), *Retispinopora lancingensis*, Gaster. Junction of abundant *O. pilula* and *Hagenowia* horizons in pit. 48 S.W.

Chalk pit 100 yards north of Downs Farm, Funtington. *Offaster pilula* Lam. 48 S.W.

Top beds of zone at 600 ft. O.D. near tumuli, 50 yards N.E. of spot "Urns found A.D. 1859," S.E. end of Bow Hill, Stoughton. 48 N.W.

Chalk pit on south side of road at S.W. end of Lambdown Hill, Stoughton. Junction of abundant *O. pilula* and *Hagenowia* horizons in pit. Pit yielded *Echinocorys scutatus* var. *cincta* Brydone, large *Echinocorys*, large *Offaster pilula* Lam. *Ostrea canaliculata* J. Sow. (see also **12**, p. 32). 48 N.W.

Junction of *Offaster pilula* and *Actinocamax quadratus* zones at 300 ft. O.D. at N.W. end of Lambdown Hill, east of Wildham Barn, Stoughton. 48 N.W.

Horizon of abundant *O. pilula* at 300 ft. O.D., N.W. end of Greatdean Bottom, one-third mile N.N.E. of triangulation spot 467 on Lambdown Hill, Stoughton. 48 N.W.

Bank of track at parish boundary on east side of Stripeshill Copse, midway between road and 300 ft. O.D., two-thirds mile N.W. of Wildham Barn, Stoughton. *Offaster pilula* Lam., *Ostrea canaliculata* J. Sow. N.W. corner of 48 N.W.

Bank of track at 400 ft. O.D., half-mile E.S.E. of Manor Farm, Stoughton. *Offaster pilula* Lam. 48 N.W.

Junction of *Offaster pilula* and *Actinocamax quadratus* zones just above 500 ft. O.D., and north of tumuli, two-thirds mile S.E. of Stoughton Church. 48 N.W.

Old Chalk pit, Adsdean Farm, Funtington. Junction of abundant *O. pilula* and *Hagenowia* horizons in pit. 47 S.E.

Top beds of zone in Upper Wood Lynch, 250 yards north of Lynch Barn, half mile north of the Fox and Hounds Inn, Funtington. *Pharetrospongia strahani* Sollas. 47 S.E.

Copse on north side of pond, Adsdean Down. *Bourgueticrinus* form 1, Brydone. 47 S.E.

Bank of lane to Inholmes Wood near 200 ft. O.D., one-third mile N.E. of Stoughton Church. *Bourgueticrinus* form 1. Brydone. 47 N.E.

South bank of lane at about 225 ft. O.D. on east side of main road, 200 yards east of Inn, West Marden. *Hagenowia rostrata*, Forbes, *Offaster pilula* Lam. 47 N.E.

Chalk pit on north side of road near B.M. 418.0, one third mile east of East Marden Church. Basement beds of zone. 34 S.W.

Chalk pit above 500 ft. O.D., quarter mile east of Faith, Hope and Charity, East Marden Down. *Hagenowia* horizon. Large *Echinocorys*. 34 S.W.

Roadside pit at B.M. 468.2, S.E. end of Apple Down, half mile north of Up Marden House, Up Marden. 33 S.E.

ZONE OF *ACTINOCAMAX QUADRATUS*.

Pit 100 yards south of Parkbottom Barn, north of Park Farm, Arundel. 63 N.W.

Roadside pit, 200 yards north of Sir George Thomas Arms, Slindon. 49 S.E.

Old pit at 200 ft. O.D. on north side of road, Court Hill, 200 yards N.W. of R.C. Church, Slindon. *Saccocoma cretacea*, Bather. 49 S.E.

Roadbank on south side at small pit on map, 250 ft. east of B.M. 119.2, half mile west of St. Mary's Church, Slindon. 49 S.E.

Pit at Crouch Ham, one-third mile S.E. of Eartham House, Eartham. *Saccocoma cretacea* Bather. 49 S.W.

Pit south of S.W. corner of Crab Row, half mile south of George Inn, Eartham. 49 S.W.

Pit, 150 yards south of Dodds Copse below 200 ft. O.D., south end of Long Down, Eartham. *Bicavea striata*, Gaster. 49 S.W.

Halnaker Chalk pit, half mile south of Halnaker Windmill, Boxgrove. 49 S.W.

At 400 ft. O.D., 150 yards north of Halnaker Windmill and in area of triangulation spot 420, Boxgrove. 49 S.W.

Pit at 200 ft. O.D. in wood, 100 yards north of Intrenchment, Valdoe, half mile E.N.E. of Lavant Lodge, Lavant. 48 S.E.

Chalk pit, 200 yards north of Trumley Copse, Lavant, Evidence of zone in south face of pit. (See *Offaster pilula* zone.) 48 S.W.

Small pit, 50 yards north of Trumley Copse, Lavant, south of last pit. 48 S.W.

Pit at north end of Inham's Lane, West Stoke. 48 S.W.

Overgrown pit on west side of lane, 350 yards north of West Stoke Farm, West Stoke. 48 S.W.

On Funtington Down below 400 ft. O.D., near Hounsom Firs Wood, 400 yards N.N.W. of Down Farm, Funtington. *Bicavea striata* Gaster. 48 S.W.

On Funtington Down, north of hedge, 100 yards south of Funtington Plantation. *Cidaris subvesiculosa* d'Orb. 48 S.W.

Just above 400 ft. O.D., north east corner of East Plantation, 200 yards north of triangulation spot 447 on Funtington Down. *Bourgueticrinus* form 7, Brydone. 48 S.W.

Pit on south side of Funtington Down above 300 ft. O.D., 200 yards S.E. of triangulation spot 334. Funtington. Zonal form of *Echinocorys scutatus* Leske, *Lunulites cretaceus* Defr. 47 S.E.

Just below 400 ft. O.D., 350 yards N.E. of triangulation spot 334, Funtington Down, Funtington. *Retispinopora arbusculum*, Brydone, *Bicavea striata* Gaster, *Cidaris subvesiculosa* d'Orb. 47 S.E.

Above 400 ft. O.D. near boundary hedge on south side, 350 yards N.N.W. of pond, Adsdean Down, Westbourne. *Saccocoma cretacea* Bather, *Bicavea striata* Gaster, *Clausa globulosa*, d'Orb., *Cistella* (*Argiope*) *bronni* von. Hag., *Crania egnabergensis*, Retz. 47 S.E.

150 yards S.W. of Old Barn at B.M. 382.4 on Walderton Down, Stoughton. *Saccocoma cretacea* Bather. *Kingena lima* (Defr.). 47 S.E.

On north side of B.R. above 400 ft. O.D., 300 yards E.N.E. of Old Barn at B.M. 382.4 on Walderton Down, Stoughton. *Bicavea striata* Gaster. 47 S.E.

On north slope of Walderton Down below B.R. at B.M. 287.3, half mile S.S.W. of Stoughton Vicarage. *Lumulites cretaceus* Defr., *Rhynchonella limbata* (v. Schloth.) 47 S.E.

Chalk pit by track, just above 200 ft. O.D., S.E. of Walderton, on west side of Walderton Down, Stoughton. 47 S.E.

Near tumuli on north side, above 500 ft. O.D., half mile S.E. of Manor Farm, west of south end of Bow Hill, Stoughton. *Saccocoma cretacea* Bather, *Bicavea striata* Gaster, *Crania egnabergensis* Retz. Base of zone. S.W. corner of 48 N.W.

At 600 ft. O.D., 150 yards east of south tumulus on north side of earthwork, south end of Bow Hill, Stoughton. *Bicavea striata* Gaster. Base of zone. 48 N.W.

Tumuli on Bow Hill, Stoughton. 48 N.W.

Junction of *Offaster pilula* and *Actinocamax quadratus* zones at 300 ft. O.D. at N.W. end of Lambdown Hill, east of Wildham Barn, Stoughton. 48 N.W.

Chalk pit, one third mile south of Telegraph Hill Farm, one-third mile S.E. of Compton Church. 33 S.E.

Pit on north side of lane, 150 yards east of Lower Farm and north of Lower Farm Copse, Up Marden. 47 N.E.

Pit, quarter mile N.E. of Pitlands Farm, Up Marden. *Cidaris subvesiculosa* d'Orb. 47 N.E.

Bank of lane near 300 ft. O.D. at spot where lane enters Inholmes Wood, one-third mile north of Stoughton Church, also in Wood between 300 ft. O.D. to spot where lane joins footpath from Stoughton Church. *Saccocoma cretacea*, Bather. 47 N.E.

Bank of lane at about 250 ft. O.D. at S.E. corner of Inholmes Wood, west of Stoughton Church, north of Vicarage. *Saccocoma cretacea* Bather, *Lunulites cretaceus* Defr. 47 N.E.

Top of field at S.W. corner of Inholmes Wood, just above 200 ft. O.D., quarter mile N.W. of Stoughton Vicarage. *Cidaris subvesiculosa* d'Orb. 47 N.E.

Bank of lane near 160 ft. O.D. at N.W. end, one-third mile N.E. of Manor Farm, Walderton. 47 N.E.

Old Chalk pit, 250 yards south of Lockash Farm, Up Marden. 47 N.E.

Roadside pit, 300 yards south of West Marden Hall, West Marden. 47 N.E.

Pit at 300 ft. O.D. in Warren Copse on east side of lane, one-third mile north of Watergate House, Up Marden. *Rhynchonella limbata* (v. Schloth.) 47 N.E.

Pit near south end of Fanny's Row, one-third mile N.W. of Watergate House, Up Marden. *Lunulites cretaceus* Defr. 47 N.E.

Pit, quarter mile east of Lodge Farm, south of Oldhouse Lane, West Marden. *Rhynchonella limbata* (v. Schloth.). 47 N.E.

Pit in Watergate Hanger at 300 ft. O.D., half mile west of Watergate House, Up Marden. *Saccocoma cretacea* Bather, *Cistella* (*Argiope*) *bronni*. von Hag. 47 N.E.

Pit in field, quarter mile W.N.W. of Brocksnapp, Stoughton. 47 N.E.

Small roadside pit, 150 yards S.E. of Brocksnapp, Stoughton. *Cidaris subvesiculosa* d'Orb. *Bourgueticrinus* form 4 Brydone. 47 N.E.

Pit, 250 yards south of Lumley Seat, Stansted Park, Stoughton. 47 N.E.

Pit at north end of Lumley Wood, quarter mile W.S.W. of Lumley Seat, Stansted Park, Stoughton. 47 N.E.

Pit in wood at 200 ft. O.D., south of Woodlands Lane, Stoughton. Top of 47 S.E.

Bank of lane at curve at 100 ft. O.D., 100 yards S.W. of Racton Church. *Bicavea striata* Gaster. 47 S.E.

Pit in field on north side of Hares Lane, Racton, 100 yards N.E. of B.M. 164.6, quarter mile N.E. of Ractonpark Farm. 47 S.E.

Small roadside pit in Hares Lane, Racton, west of spot 123, 250 yards north of Ractonpark Farm. 47 S.E.

Pit 250 yards S.W. of Racton Monument, Racton, also pit 400 yards S.W. of Monument. 47 S.E.

Pit at south end of Hams Copse on south side of Racton parish boundary, half mile west of Racton Monument. 47 S.E.

Pit in field on south side of Park Lane, quarter mile N.W. of Sindle's Farm, south of Stansted Park, Stoughton. *Saccocoma cretacea* Bather, *Bourgueticrinus* form 7. Brydone. 47 S.E.

Pit at parish boundary, quarter mile west of Sindle's Farm, south of Stansted Park, Racton. 47 S.E.

Pit in field, south of Markwells Wood, one-third mile N.E. of South Holt Farm, Compton. *Lunulites cretaceus* Defr. 47 N.W.

Pit at 300 ft. O.D., 250 yards E.N E. of South Holt Farm, Compton. 47 N.W.

Pit at 300 ft. O.D., Shortleys Copse, Up Marden, 250 yards north of Northwood Farm, Forestside. *Rhynchonella limbata* (v. Schloth.). 47 N.W.

Pit on south side of road, one-sixth mile north of Church, Forestside. 47 N.W.

Pit on north side of footpath, Warren Down, Forestside, one-third mile west of Church, also pit on south side of footpath the same distance W.S.W. of Church 47 N.W

Pit at west end of Stansted Forest, one-sixth mile south of Drew's Farm, Forestside, one mile S.W. of church. 47 N.W.

HAMPSHIRE. Brydone's pit No. 1023. Blendworth Down, one-third mile north of New Barn, Blendworth. *Bicavea striata* Gaster. *Pentacrinus* sp. *Kingena lima* (Defr.) small, *Metopaster Parkinsoni* Forbes (large). 68 N.E.

Brydone's pit No. 1024, 300 yards S.E. of Pit No. 1023, north of New Barn Farm, Blendworth. 68 N.E.

Pit, 60 yards N.E. of N.E. side of New Barn Farm, Blendworth. 68 N.E.

The following 1914 Edition of the six-inch Sheets of the Ordnance Survey were used in the field work and preparation of the Zonal Map, and also for the descriptions of the evidence included in this paper :—

Sheets 50 N.W. 50 S.W. 63 N.W. 35 S.E. 35 S.W.
49 N.E. 49 N.W. 49 S.E. 49 S.W. 62 N.E.
34 N.E. 34 N.W. 34 S.E. 34 S.W. 48 N.E.
48 N.W. 48 S.E. 48 S.W. 20 S.E. 33 N.E.
33 N.W. 33 S.E. 33 S.W. 47 N.E. 47 N.W.
47 S.E. 47 S.W.

Since June, 1934, the travelling expenses in connection with the field work were defrayed out of a grant from the Government Grants Committee of the Royal Society. This is acknowledged with thanks.

Thanks are also due to Mr. G. E. Jomaron for drawing the black and white copy of the Author's Map..

I am again indebted to my wife, who has assisted me in many ways, especially in the field.

Finally I have to record my gratitude to the Southern Railway Company and others who have allowed me to enter on their lands for the purposes of geological investigations.

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FIELD MEETING AT WATEREND, NORTH MIMMS, HERTFORDSHIRE

Sunday, 2nd April, 1944.

Report by the Director : P. Evans, M.A.

Members of the Association joined with members of the Hertfordshire Natural History Society and Field Club in a visit to the swallow-holes at Water End, North Mimms. The party of 24 would probably have been larger had there not been rain overnight and earlier in the day, but the extra flow of water added to the interest of the swallow-holes.

The Director contrasted the Chiltern valleys which are dry in their upper parts with the valley of the Mimmshall Brook, which is dry in its lower part. The valleys of the Chilterns begin high above the water-table in the Chalk and springs appear where the valley reaches the level of the water-table. The Mimmshall Brook is one of the few streams rising on the Tertiaries and flowing northwards towards the Chalk, which it reaches *above* the water-table ; consequently the stream disappears underground to continue through channels in the Chalk. There are a number of swallow-holes in the area, but those in the Mimmshall Brook and its tributaries are the best and most accessible. They were described by S. W. Wooldridge and J. F. Kirkaldy (*Proc. Geol. Assoc.*, xlviii, 1937, p. 307), who pointed out that there has been a slight uplift of the Chalk in this area and discussed the form of the water-table.

The party were able to see the water of the Mimmshall Brook pouring into various swallow-holes, the stream being directed from one hole to another by the removal of small banks that had been put across the stream at convenient points earlier in the day. The Director referred to the high level of the water after a flood in April, 1942, and Mr. R. Butler showed photographs taken during an exploration made in 1928, when it was possible to descend some 30 or 40 feet into a newly-formed swallow-hole. Members then inspected the Potterels tributary stream and the ' collapsed area ' in its course.

The meeting concluded with tea at a near-by cafe, and a vote of thanks to the Director.

FIELD MEETING AT BARRINGTON, NEAR CAMBRIDGE

Saturday, 27th May, 1944.

Report by the Director, Professor W. B. R. King, O.B.E., M.A., Sc.D., F.G.S.

By the courtesy of Messrs. Eastwoods Cement Co. Ltd., a field meeting was held in perfect weather at their Barrington pit, some 17 members coming by train from London and about the same number from Cambridge.

After Professor King had explained the general section and the problems involved, the party examined in detail the excellent exposures of the Cambridge Greensand. The irregular clearly defined base of the glauconitic sandy marl with its numerous phosphate nodules resting on the Gault was well seen, as was the gradual passage upwards into the Chalk Marl. At several points there appeared to be thin beds of the glauconitic sand below the obvious base of the Cambridge Greensand with Gault clay both above and below. It was suggested that the upper part of the clay may have been puddled and settled as pure clay above the whisps and pockets of sand.

After spending much time on the Greensand exposures where a good number of fossils were obtained (which Mr. Brighton kindly identified for the members), the party worked fairly quickly up the section to the glacial deposits on the top of the hill. The Director pointed out the sharp junction with the Chalk with its deeply channelled surface and emphasised the difficulty in arriving at conclusions regarding the relative ages of this boulder clay and the Hippopotamus-bearing gravels of Barrington village.

Members collected numerous Jurassic fossils and rocks and noted the large number of well striated boulders of hard white chalk and the numerous specimens of grey flint, all indications that this drift had come from a practically due northerly direction. The fact that very little decalcification had taken place in the drift was also noted.

On the way from the top of the hill, the Burwell Rock facies was noted with its characteristic brown phosphate nodules.

The party had an excellent tea, which Dr. E. Dix and her students had brought from Cambridge.

Note by the Secretary for Field Meetings. Professor King, with his usual modesty, omitted to add that he and Mrs. King were, with Dr. E. Dix, jointly responsible for supplying the tea. During this, a vote of thanks to Professor and Mrs. King, Mr. Brighton and Miss Dix was proposed by Dr. K. P. Oakley and carried with acclamation.

FIELD MEETING AT ELMSTEAD WOODS, KENT

Saturday, 22nd July, 1944.

Report by the Director, ARTHUR WRIGLEY.

Although by a postal failure, the July circular did not reach most Members until a day or so before the field meeting and despite wailings around and racket aloft, seven Members carried out the programme to the letter, excepting that the Director had to interrupt his discourse while overhead a flying bomb snorted Londonwards. The well-known Rock-Pit in Sundridge Park was visited, but a full report of what was seen is deferred until the meeting is repeated.

FIELD MEETING AT WEST WICKHAM, KENT

Saturday, 13th May, 1944.

Report by the Director, ALAN WOOD, B.Sc., Ph.D., F.G.S.

Assembling at West Wickham Station, a party of thirty-five Members and friends went obliquely up the dip-slope of the Tertiaries to the outcrop of the Blackheath Beds in Woodland Way (*Proc. Geol. Assoc.*, lv, p. 21). These beds, and the Reading Beds below, were examined. While descending the valley-side to the south-east, it was made clear how rain-wash, taking stones from the Blackheath Beds down the hillside, over the top of the lower beds, gave a false idea of the limits of the formation. At the foot of the slope an alluvial flat and the Chalk hills at the other side of the valley were seen. The Thanet Sand was well exposed a hundred and fifty yards to the north-east, and it was clear that there was no room for the Chalk to crop out between it and the alluvial flat. The line of the Bourne, which rises in the floor of the valley during wet winters, could be seen and it was interesting to see that houses had lately been put up right across it.

On proceeding to the new road section it was found that Thanet Sand had been exposed in the back garden of No. 7, Seabrook Drive, while Woolwich and Reading Beds were newly uncovered in the front garden of No. 12. These new facts make necessary a change of the line given on the sketch-map of Himus and Wood ; the correct line between Thanet Sand and Woolwich and Reading Beds lying nearly 50 yards farther to the north-west. In the cutting itself, Mr. A. G. Davis, clearing the side, discovered the Bottom Bed of the Woolwich and Reading Beds, with rounded flints imbedded in soft sand.

Fossils were obtained from the Shell Band in the Blackheath Beds, and some members saw the solution effects in these beds.

A good section in the alluvial flat was seen in the gravel workings in Tie Pigs Lane. Unrounded flints rested sharply on Thanet Sand, and the President (Mr. A. S. Kennard) suggested that these deposits were caused by solifluction, during the later stages of the Glacial Period.

The meeting was concluded by a vote of thanks which was proposed by the President.

CONTRIBUTIONS TO DISCUSSIONS.

Dr. K. P. OAKLEY'S REPORT
on
"MAN THE TOOL-MAKER"
Vol. lv, 1944, pp. 115-118.

Mr. EDWARD LAWRENCE, F.R.A.I. : In the above article it is claimed that man is the only animal capable of abstract thinking, a condition of mind which is there defined as one capable of "imagining, of deducing from and speculating on relationships between things. *This abstract thinking has led to science, art and religion*." [The italics are mine.]

Thus it follows that where there is no abstract thinking there can be no religion, no art and no science. But religion, art and science exist among primitive races, who are not literate, and also exist among ourselves who are literate, but whose thoughts are, for the most part, of a concrete character. The ancient Romans were a civilized people as that adjective is usually understood. Professor Granger, however, declared that they lacked the "capacity for abstract thought." As regards "abstract thought" we can only judge the ancient Roman by his literature, as we must also judge ours. It does not follow because people can now read that they also can think ; most "thought" so-called is "feeling" and not logical thinking.

Science itself is usually regarded as a late phase of human thought. By "science" is meant exact, uncontradictable knowledge. But as science, art and religion belong to so-called savages as well as to civilized men, and as savages are not abstract thinkers, but have a very extensive concrete vocabulary, it will be obvious that science and art and religion are very old and are not necessarily the outcome of abstract thinking, as Dr. Oakley would have it. Professor Malinowski has claimed that primitive man was and is a scientific man. He says : "The widespread misconception that primitive man has no rudiments of science, that he lives in a hazy, mystical, or infantile world, has to be rejected in the light of our fuller knowledge of primitive cultures," for systems of knowledge exist among the lowest primitives and must have existed from the very beginning of humanity. "Metaphysics and religious speculation are as old as knowledge and as old as language itself."

That many current conceptions of "savage" life and "savage" thought have been built upon very sandy foundations are proved conclusively by early statements that the "primeval savage" was a "terrific roaring, yelling, biting and fighting" creature, as was "scientifically" asserted ; a statement as grotesque as it is untrue.

Dr. K. P. OAKLEY : Mr. Lawrence would appear to agree with me that Palaeolithic Man may be considered on the evidence available to have been capable of "religion, art and science," but he disagrees with my assumption that these imply a capacity for abstract thought. Our disagreement on this point is due to our setting different limits to the meaning of the term abstract.

Art, science and religion, however primitive, surely imply respectively capacities for imagery, deduction and speculation, all of which involve a certain measure of abstraction from perceived reality. Such thinking is more usually termed *conceptual*, as distinct from *perceptual* (of which apes are capable). The beginnings of conceptual thought are evident in the activities of the most primitive men known ; for instance, language implies it.

Having regard to the average museum visitor, for whom the exhibit "Man the Tool-maker" was primarily designed, it seemed to me that the term *abstract* was more likely to strike a chord than *conceptual*. I have since noticed that Dr. C. K. Ogden in his "A.B.C. of Psychology" (1944) refers to "abstract, or conceptual thinking" (p. 96).

One more point. I would agree that even the purest conceptual thought may be tinged with feeling (*affect*). The Magdalenian artist " doubtless found pleasure in so exercising his image-forming* faculty," to quote my own words.

" A NEW SECTION IN THE LOWER LONDON TERTIARIES NEAR WEST WICKHAM, KENT."

By Drs. G. W. Himus and Alan Wood,

Vol. lv, 1944, p. 21.

Mr. E. E. S. Brown writes from Rio de Janeiro :—

This careful account of a new section in the Lower Tertiaries is of considerable value and it will be historically interesting that our *Proceedings* record the assistance to mapping afforded by bomb-craters.

Stratigraphy. The occurrence of a " shell bed converted into hard stone " nearly at the base of the Blackheath Beds is in a position normally to be expected in such permeable strata, but is not very common in that position in these beds. The conglomerate, not seen *in situ*, mentioned in paragraph 3, page 23, is presumably distinctive from the above, and probably occurred in lenticles either in the highest pebbly sands, just under the thin London Clay cover, or from higher beds in the Blackheath Series in the vicinity. Massive but lenticular shelly conglomerates are very characteristic in this last position over a wide area and notably at Swanscombe Hill, Bromley Hill, Charlton and Eltham. In fact at Swanscombe, before the arterial road was cut through the hill, this conglomerate was erroneously recorded as the basement-bed of the London Clay. The pebble beds with sandy matrix, below the conglomerate, are usually devoid of calcareous fossils, but sometimes rich in fish-teeth. The conglomerate appears to have been formed when there was a high-water-table, by percolating water, saturated with calcium carbonate from the disolved shells below, and the position of its formation was controlled by the impermeable London Clay above. Similarly calcareous hard bands at the base of the Blackheath Beds were formed, more rarely, when the water-table was lower and their position was controlled by the silts and clays of the Woolwich Beds below.

Palaeontology. The record " *Cyrena sp. tumid* form (frequent) " is of much interest. Mr. A. G. Davis will remember that at the Cobham Wood section he and the writer found some small tumid Cyrenas which were rather rare but quite distinctive. Specimens were deposited in the British Museum and Geological Survey collections, but were not then described, because further material was awaited in view of the following circumstances. Edwards described and figured in his Monograph on Tertiary Bivalves, *Cyrena tumida*, from the Caleb Evans collection, but this type specimen was about three times the size of the Cobham Wood tumid forms. Correspondence with the British Museum disclosed that only part of the Caleb Evans collection reached the Museum, and it was concluded that the type specimen had been lost. The new record of frequent occurrence provides, therefore, the first opportunity to establish, according to the size range of the new specimens, either a neotype to replace the lost type specimen or to describe a new species of *Cyrena* which may be confined to the Blackheath and Woolwich series.

I regret that, being abroad, I am unable to add the appropriate references, but, with the exception of the Monograph, they are all in the *Geol. Assoc. Proceedings* and the relative papers may be traced from the place names quoted.

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* Misprinted *imagine-forming*.

THE CARBONIFEROUS ROCKS OF THE SWINDEN ANTICLINE, YORKSHIRE

with a Redefinition of the Boundary between Tournaisian and Viséan in England.

By R. G. S. HUDSON, D.Sc., F.G.S., and H. V. DUNNINGTON, B.Sc.

[*Received 14th January, 1944.*]
[*Read in abstract, 7th July, 1944.*]

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I. INTRODUCTION.

SOUTH of Hellifield and between the Ribble and the Aire (see Fig, 20) the central part of the Craven Lowlands consists of numerous, low, rounded hills rarely rising above 700 ft. O.D. The district is mainly pasture land with occasional meadow and has long been famous grazing country. Natural exposures of Carboniferous rocks whether on hill-side or in stream-bed are rare, since the country is mostly blanketed with drift, while the numerous small quarries are not now worked. Yet, since the geology of the area is important because of its position between the recently described areas of Skipton, Eshton-Hetton, Slaidburn and Clitheroe, an attempt has been made to map it on the six-inch scale and to build up a succession for comparison with those of the surrounding areas.

The area is occupied by the structure known as the Swinden Anticline, one of the many extensive N.E.-S.W. folds that occur in the Craven Lowlands (Fig. 20). The anticline is presumably a continuation of the Gisburn Anticline to the south-west and is continued to the north-east in the Eshton Anticline. It is, however, separated from these structures by N.W.-S.E. faults respectively known as the Barnoldswick and Gargrave Faults, the latter being a member of the South Craven Fault system. To the north and south there are extensive areas of drift-covered country and only to the south-east can the outcrops be mapped into those of the neighbouring structure, the Bank Newton Syncline (Fig. 20).

Most of the rocks are either dark grey limestones or calcareous shales. They are not very fossiliferous and most of the fossils which were once available have already been collected. It has not, therefore, been possible to make extensive collections. The common fossils are *Caninia*, *Syringopora*, '*Zaphrentis*,' *Pustula*, and '*Orthotetes*,' and use has been made of these forms in the determination of the age of the beds. The oldest rocks in the area are not exposed, but probably belong to the *Zaphrentis* (Z) zone, while the uppermost fossiliferous beds contain an upper C_2 fauna : most of the succession, therefore, is of Tournaisian age. The total thickness is, very approximately, about 3,000 feet. Those beds which have a more or less constant lithology are grouped together and named : where the characters of such lithological groups differ from those on the same horizon in other areas they are given local names.[1]

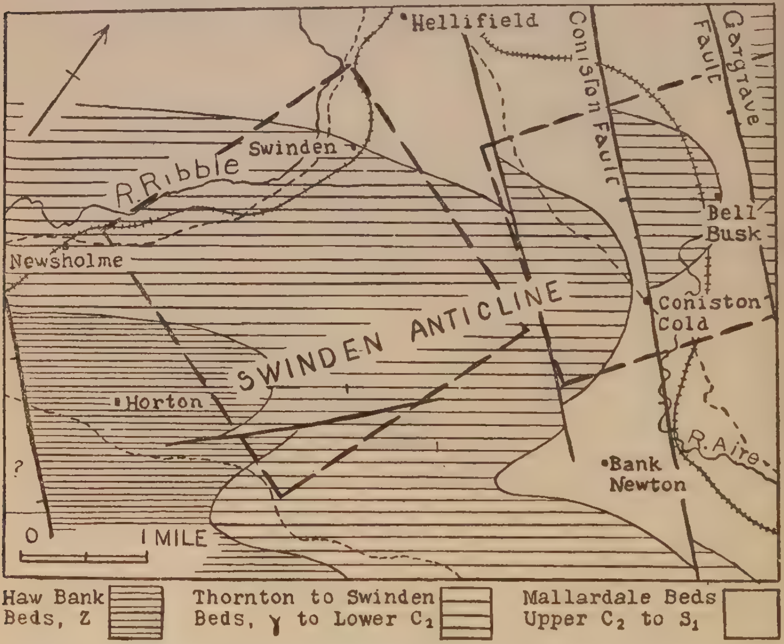

FIG. 20.—Sketch map of Swinden Anticline showing the relative positions of the Swinden Moor area and the Coniston Cold area, and the position of the anticline between the Barnoldswick Fault (the unnamed fault on the left-hand side of the sketch-map) and the Gargrave (South Craven) Fault.

The anticline is apparently a comparatively simple structure, for the numerous small faults which can be seen in most of the quarries have little effect on the outcrop of the various beds, while the variation in dip over the anticline is remarkably regular. To the north, however, two faults—the Hellifield and Coniston Cold Faults—cross the pitching nose of the anticline (Fig. 20). These faults downthrow to the south-west and have considerable lateral movement, shifting the axis of the anticline to the north-west. The succession in these two fault slices differs considerably from that in the main part of the anticline and resembles that in the Eshton Anticline across the Gargrave Fault. The stratigraphy of the two areas, the Swinden Moor area, which includes the main part of the anticline, and the Coniston Cold area, which includes the two fault slices between the Hellifield and Gargrave Faults, are therefore described separately.

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[1] It is useful to have names for the main lithological divisions of the Lower Carboniferous of the Craven Lowlands that can be applied to the succession in any area. Following Parkinson (1936) it is suggested that Tiddeman's names of Clitheroe Limestone, Shales-with-Limestones and Pendleside Limestone be so used. At Skipton, Broughton and Clitheroe the top beds of the Clitheroe Limestone are respectively the Embsay, Broughton and Salt Hill Limestones, probably not quite all on the same horizon but sufficiently so to facilitate a general comparison of the succession in the various areas. With the exception of the shales with limestones (Mallardale Shales-with-Limestones) at the top of the succession, all the beds in the area under consideration belong to the Clitheroe Limestone.

The area of the Swinden Anticline was mapped by Gunn and Tiddeman and is included in the one-inch Geological Survey maps, Sheets 61 and 68. No memoir on either sheet was published, though references to certain exposures in the southern part of the area are made by Gunn in the Burnley Memoir (Hull *et al.*, 1875). On the maps, the beds in the centre of the anticline (now known to be of Z-C_1 age) were coloured dark blue and correlated with the Clitheroe Limestone, while the surrounding beds (now known to be of C_1 to D age) were coloured light blue and correlated with the Shales-with-Limestone. These correlations are now proved to be incorrect, since the uppermost beds of the Clitheroe Limestone are of upper C_2 age. Later, Wilmore published several papers (1906, 1909, 1910, 1912) on the Carboniferous Limestone of the Craven Lowlands and made brief references to the lithology and fauna of some of the exposures in the Swinden Anticline. In his latest published paper (1912), he recognised that some of the beds were of Tournaisian age. Since then almost the only reference to the geology of the area is a brief note by one of us (Hudson, 1929), in which attention is called to the exposure in the quarries at Swinden and Nappa of beds belonging to the *Caninia* zone.

II. GENERAL STRATIGRAPHICAL SUCCESSION.

The beds exposed in the main part of the Swinden Anticline are mainly evenly bedded, dark grey limestones and calcareous shales. The limestones are finely detrital and usually contain abundant foraminifera; they are often dolomitic and occasionally cherty. Macroscopic fossils are rare, though at some levels a caninoid phasal fauna of *Caninia*, *Siphonophyllia*, *Chonetes* (*Daviesiella*) *comoides* group, *Pustula* and occasional semireticulate productids is fairly common. Light-coloured limestones, however, do occur in the lower part of the succession. They are not well bedded and are poorly fossiliferous and in one part of the Swinden Moor area they pass into the non-bedded light-coloured reef-limestones with their shelly reef-fauna. The shales are usually coarse, unfossiliferous, and contain thin limestones; occasionally they may be very crinoidal or contain fossils of zaphrentoid phase. The forms usually known as *Rhipdomella michelini* and *Athyris roysii* are common in these faunas throughout the succession of the area and are not included in the faunas listed in the following pages.

In general the succession is of the limestone-with-shales facies and is comparable to that exposed in the Skipton, Broughton and Thornton Anticlines. As in those areas, the succession can be divided into groups of beds, each consisting of a lower series of limestones-with-shales and an upper series mainly limestone. Only the succession in the upper groups can be determined with any certainty since beds of the lowest, and by far the thickest, group are not exposed: their nature and age is inferred from their stratigraphical position. The names, Haw Bank, Thornton, Nappa and Swinden, given to these groups are those of districts in the Craven Lowlands where those beds are best exposed.

In the Coniston Cold area, where outcrop is confined to the upper part of the succession, there is, in general, more limestone than in the beds of the same age to the south-west. The main feature of this area is the occurrence of reef limestones and boulder beds replacing the upper part of the normal succession. The general succession is as follows :—

	Thickness in feet.
Mallardale Shales-with-Limestones (Upper C_2 and S_1)	300+
Toft Hill Limestones and Shales (Upper C_2)	80
Swinden Limestone (C_2)	60
Swinden Shales-with-Limestone (Lower C_2) with Fogger Reef Limestone...	450
Nappa Limestone (Lower C_2)	50
Nappa Shales-with-Limestones (C)	300
Thornton Limestones (C_1) with Newsholme Reef Limestone)	450
Thornton Shales-with-Limestones ($\gamma - C_1$)	500–600
Haw Bank Beds (Z)	500–1000

III. THE SWINDEN MOOR AREA.

(a.) Haw Bank Beds.

Inside the outcrop of the Thornton Beds the central part of the Swinden Anticline occupies an extensive area extending nearly as far south as Bracewell. South of the area shown on the map (Pl. 10), the axis of the anticline presumably passes somewhere near Horton (Fig. 20) and near there, in Stock Beck east and west of Horton Bridge, is the only group of exposures of any value. Shales with thin limestones are exposed : no fossils of diagnostic value have been collected. The dip of the beds is not always regular owing, possibly, to the proximity of the Barnoldswick Fault, but in general the shales in the beck west of the bridge have a northerly dip and those east of the bridge a south-easterly dip, suggesting that the axis of the anticline runs between them. If this is so, then they are almost the lowest beds in the anticline and, unless the intervening beds are repeated by faulting, must be from 500 to 1,000 feet below the base of the Thornton Shales-with-Limestones. This position would place them in the Haw Bank Limestones-with-Shales (Hudson and Mitchell, 1937 ; Hudson, 1944) of Z age, an allocation not out of keeping with the age of the beds outcropping in the centre of the neighbouring Broughton and Skipton Anticlines

(b.) Thornton Shales-with-Limestones.

These beds are not well exposed nor, over the greater part of the area, do they form strong features, though their outcrop is often marked by comparatively extensive ‘flats.’ On the eastern side of the Marton Fault at the foot of Marton Scars, their dip is steeper and there they form a slack occupied in part by Skelda Bottoms. A massive but not very fossiliferous limestone occurs in the lower part of these beds and has been quarried near Gledstone Kennels. There about ten feet of fossiliferous shales with thin limestones overlie about 50 feet of thick-bedded limestone. *Cyathaxonia cornu* Mich. and *Fasciculophyllum ambiguum* (Carr.) are quite common in the shale, which also contains *Caninia cornucopiae* (Mich.), *Fasciculophyllum omaliusi* (Ed. and H.), *Syringopora* spp., *Spirifer tornacensis* de Kon., *Euomphalus* sp., and other elements of a zaphrentoid fauna. Wilmore (1906, p. 42) records *Caninophyllum patulum* from here.

The greater part of the beds in the slack is not exposed, but at the foot of Marton Scar, two old quarries (Y and Z) expose about 85 feet of beds consisting of fifteen feet of black flaggy limestones and shales below more massive and dolomitic limestones. The shales are very crinoidal, large unbroken columns being common. The other common fossils are *Fenestella* spp., *Actinoconchus planosulcatus* (Phill.), *Cleiothyridina glabristria* (Phill.), *Pustula tenuipustulosa* Thomas, and *Schellwienella aspis* Smyth. Occasional Zaphrentids have also been found. The position and composition of the fauna suggest that it is of C_{I} age, while that of the Gledstone Kennels Beds may well be of γ age. The total thickness of the Shales-with-Limestones would seem to be about 500-600 feet. In the Thornton Anticline these beds are best exposed in the old quarries about half a mile south-west of Thornton and north-west of Thornton Hall Quarry (Wilmore, 1909, p. 354).

(c.) Thornton Limestones.

These rocks are the best exposed of all that outcrop in the area under consideration. The lower part is light-coloured limestones which are well bedded and form natural escarpments as at Marton Scars, or which as at Newsholme, are ' reef ' limestones tending to form knolls and containing a characteristic fauna. The upper beds are either dark grey, mainly unfossiliferous, dolomitic limestones, or dark grey argillaceous limestones with hard calcareous shales, often comparatively fossiliferous. *Fasciculophyllum densum* (Carr.), *Daviesiella* cf. *comoides* (Sow.), *Pustula interrupta* Thomas, and *Pustula nodosa* Thomas are characteristic fossils of the lower division and *Plicatifera humerosa* (Sow.) and *Syringopora reticulata* Goldf. of the upper beds. *Conocardium* and large gastropods are not uncommon in some beds and *Amplexus coralloides* is the common fossil of the reef limestone.

Lower Thornton Limestones

The succession of these beds is best seen in the escarpment of Marton Scars where it consists of two groups of light-coloured fragmental limestones, each about 70 feet thick, separated by about 30 feet of shales and level-bedded argillaceous limestones. The upper part of the lowest light-coloured limestones is exposed in the Lower Scar and is well-bedded light grey limestones with chert nodules. Fossils are rare, but *Caninia cornucopiae*, *Fasciculophyllum densum*, *Daviesiella* cf. *comoides*, *Plicatifera humerosa* s.l. and *Pustula nodosa* have been found. The shales and dark silty limestones are partly exposed in Middle Scar, but are not fossiliferous. The lower part of the succeeding light grey limestones is poorly exposed in Upper Scar and fossils are rare. Their upper part is better exposed in small quarries (as X) to the north of the scar ; the beds here are crinoidal and *Daviesiella comoides* group, *Dictyoclostus multispiniferus* Muir-Wood, *Leptaena analoga* (Phillips), *Pustula pilosa* Thomas and *Schuchertella wexfordensis* Smyth have been collected.

On the western flank of the anticline the Lower Thornton Limestone is exposed in three quarries north of Newsholme. The most important exposure is that of Dobber Quarry, in which the fauna and lithology are those of ' reef ' limestone. Part of the rock exposed is a tufaceous limestone with regular bands of tufa about six inches apart : other limestone is fairly fossiliferous with *Amplexus coralloides* and various pustulids as the common fossils. The limestone is much broken by fault fractures and there is a small N.-S. anticline, but in general the dip, which varies from 10° to 70°, is steeply to the north-west, which is the direction of the regional dip. The fauna from the quarry includes

Amplexus coralloides Sow.
Cleiothyridina glabristria (Phill.)
Dictyoclostus teres Muir-Wood
Dictyoclostus spp.
Dielasma hastatum (Sow.)
Plicatifera mesoloba (Phill.)
Pugnax spp.
Pustula interrupta Thomas
P. nodosa Thomas
P. pilosa Thomas
Spirifer cf. *coplowensis* Parkinson
Capulus sp.
Schizostoma catillus (Mart.) and other gastropods.

Pustula nodosa and *Plicatifera mesoloba* were recorded by Thomas (1914, pp. 287 and 329) from this quarry. The fauna is of C_{I} age.

The eastern extension of Dobber Quarry shows well-bedded limestones dipping under those of the quarry, while farther to the north-west across the Newsholme-Nappa road there are exposures of bedded limestone dipping off the reef limestone. Of the two exposures to the south-west, one (R) is in the light-coloured porcellanous limestones so often a component of 'reef' limestone, while the other (S) exposes bedded limestone and some shale with thin limestones. The beds in this quarry are both folded and faulted, so that their relative position is obscure: they are, however, apparently below the limestone of Dobber Quarry.

The area marked on the map as Newsholme Reef Limestone is apparently a complex of these various limestones collectively known as 'reef limestones.' The fauna is that of the C_1 reefs of Coplow (Parkinson, 1926) and Waulsort (Demanet, 1923), while the tufaceous limestone is very similar to that of the Knott (or Sugar Loaf) in the Slaidburn area (Parkinson, 1936). Reef limestone is also exposed in a quarry west of Flamber, and it seems possible that the limestone between it and Newsholme is all of reef facies. The reef limestone is apparently the lateral equivalent of part or all of the Lower Thornton Limestone of the Marton Scars area, since the fauna is similar and both limestones are followed by the Upper Thornton Limestones. It is probable that it represents only the upper part of this limestone and that the bedded limestones of eastern Dobber Quarry and Quarry S represent the lower part.

Upper Thornton Limestones

These beds commence with crinoidal shales which are not so well exposed here as in the neighbouring Broughton Anticline. They are, however, seen in a beck section (Q) north-west of and dipping off the Newsholme reef. The run of the boundary between the shales and the limestone suggests that the reef extends upwards through the shales. The shales are followed by dolomitic limestones with a characteristic hummocky bedding and about 80 feet thick. Chert nodules are common in their upper part. They are well exposed in Hulls Delf near Newsholme and also in a series of quarries (as U and V) on both sides of the road east of Marton Scar. Occasional platy beds contain compressed specimens of *Pustula* and *Daviesiella comoides* group, but in general the fossils have been dolomitised and their details obliterated.

The dolomitic beds are followed by a considerable thickness of dark grey limestones, sometimes dolomitic, sometimes level-bedded and argillaceous. Partings and beds of shale up to a foot thick are common. Near both the base and the top of this group of beds these shales are thicker and usually very crinoidal. *Plicatifera humerosa*, *Daviesiella comoides* group and *Syringopora reticulata* are fairly common, otherwise fossils are rare. These beds are exposed in quarries (as N and O) to the south of the road across Swinden Moor; near Swinden Moor Head, the northern boundary wall of this road, is a well-known collecting place for *Plicatifera humerosa*. The crinoidal shales at the base are exposed in the quarries at High Laithe, and the shaly beds near the top of the group are exposed in a quarry (P) in the east of the area. Fossils collected from here are chiefly compressed specimens of *Pustula*, *Dictyoclostus*, *Schellwienella* and the other usual elements of the argillaceous limestone fauna. The Upper Thornton Limestone is considered to be about 250 feet thick, giving a total thickness of 450 feet for the Thornton Limestones. They are considered to be of C_1 age throughout.

(d.) Nappa Shales

These shales are exposed only in the upper part of Swinden Gill (K and J) and in the Ribble near Nappa. They are estimated to be about 300 feet thick. Over most of the area under consideration, and especially to the east of it in the Bank Newton Syncline, the shales form a rushy flat or slack. The sparse fauna collected does not enable the position of these beds in the *Caninia* zone to be determined.

(e.) Nappa Limestone.

Both the fauna and lithology of this limestone make it conspicuous in the great thickness of shales and limestones which occur between the Thornton Limestone and the Swinden Limestone. In the area under consideration the limestone is well exposed in an old quarry (M) north of Cobers Laithe and in a quarry and natural exposures (H) on both sides of Swinden Gill (the quarry here is that referred to by Wilmore, 1910, p. 543, as Swinden Gill Head Quarry). The limestone is massive bedded and slightly dolomitic with chert nodules and marked shale partings; it is about 50 feet thick. The fauna shows a welcome change from that of the beds below. *Siphonophyllia cylindrica*, *Chonetes* sp. (=*C.* cf. *papilionacea* auctt.), *Chonetes* (*Daviesiella*) *comoides* group, including a large form with a strong laterally curved pedicle valve, *Plicatifera humerosa* and varieties, and '*Orthotetes*' sp. are fairly common, while *Fasciculophyllum ambiguum* mut. α Smyth, *Michelinia megastoma*, *Syringopora* spp., *Dictyoclostus multispiniferus* and other productids, have been collected. Various gastropods and lamellibranchs also occur here. There is considerable variation among the specimens of *Siphonophyllia cylindrica*, but the common form is that figured by Wilmore, 1910, Pl. xxxix, Figs. 4 and 5. In it the zone of extra septal dissepiments is narrower and has more septal traces than in *S. cylindrica* (Scouler, Lewis), but is not so narrow as in the upper C_2 forms, such as *S. hettonensis* (Wilmore). It is a slightly more advanced form than *S. cylindrica* mut. γ Vaughan. The fauna is linked with that of the beds above and is therefore placed as of lower C_2 age.

(f.) Swinden Shales.

These beds are shales with a considerable amount of limestone, especially in their lower part. They are estimated to be about 450 feet thick, of which certainly more than half is well exposed in Swinden Gill (as G) and its tributary Mallardale Beck (as C), in an exposure (M) near Cobers Laithe, and in the Ribble north of Nappa (L). The beds may be grey calcareous shales with thin beds of dark grey flaggy limestones or brownish calcareous shales more or less sandy, with little limestone and for the most part unfossiliferous. The occasional more massive limestones may be finely fragmental, flaggy and argillaceous, or dark grey, splintery and dolomitic with much disseminated pyrites. Fossils are restricted to bands and may be locally abundant. The fauna, especially towards the base of the series, is usually of zaphrentoid phase with abundant *Fenestella*. Large crushed specimens of *Siphonophyllia* also occur. The fauna of the grey, brownish, shales often consists of athyrids, *Spirifer*, *Orthotetes* and no zaphrentoids. Crinoid debris is locally abundant. Occasional bands may contain a very prolific lamellibranch fauna, the specimens being mainly thin-shelled, crushed and indeterminate. The general fauna includes *Fenestella* spp., *Cyathaxonia cornu* Mich., *Fasciculophyllum ambiguum* var. α Smyth, *Siphonophyllia* [*Campophyllum*] cf. *caninoides* (Sibly), *Siphonophyllia* sp., probably a phasal form in the *S. cylindrica* group, '*Zaphrentis*' spp., *Michelinia* cf. *megastoma* (Phillips), *Syringopora* cf. *reticulata* Goldf., *Athyris* cf. *expansa* Phillips, *Camarotoechia*, *Composita*, *Overtonia* cf. *fimbriata* auctt., *Productus* spp., including *Dictyoclostus* and *Pustula*, *Schellwienella*, *Syringothyris cuspidata* group, *Spinocyrtia* cf. *laminosa* (M'Coy), papilionaceous and small chonetids, *Aviculopecten*, *Cardiomorpha*, *Edmondia*, *Bellerophon*, *Euomphalus*, *Loxonema*, and trilobite fragments.

(g.) Swinden Limestone.

This limestone outcrops in the north-west part of the area, where it forms a range of hills which include Tofts Hill, Mallardale Hill and Middlesber. It is very well exposed in the Ribble (F), in a quarry at Swinden Clints, in Tofts Hill railway cutting (E), and at Mallardale Beck Quarry (B). The limestone is dark blue-grey, finely fragmental, and contains occasional chert nodules. It is about 60 feet thick and includes occasional shale bands. Fossils were once common in the quarries and in the Ribble section. They include *Siphonophyllia* cf. *caninoides* Sibly, *Cravenia* sp., *Fasciculophyllum omaliusi* group, *Koninckophyllum* sp., *Siphonophyllia* cf. *hettonensis* Wilmore (cf. *S. cylindrica* mature form Vaughan), *Zaphrentis konincki* Ed. and Haime wide-angled form, *Michelinia megastoma* (Phillips), *Syringopora* sp., *Chonetes papilionacea* group, *Composita gregaria* (M'Coy), *Daviesiella comoides* group including large slightly carinate forms, *Dictyoclostus* sp., *Pustula interrupta* Thomas and other pustulids, *Schellwienella* and *Euomphalus* sp. (fairly common). The fauna is considered to be of C_2 age.

(h.) Toft Hill Limestone and Shales.

Though these beds are poorly exposed and only about 80 feet thick, yet their fauna is sufficiently distinctive for them to be regarded as a separate division. They consist of a lower 50 feet of shales and thin limestones and an upper 30 feet of fine-grained, black, silty limestones. The shales and thin limestones are exposed, though poorly, above the Swinden Limestone of Toft Hill railway-cutting (D) and in the Ribble. The limestone is exposed at Swinden Lane End and in the Ribble. The only significant fauna is that occurring near the base of the group in a shale band about nine inches thick and exposed in the railway-cutting. In addition to small brachiopods the fauna includes *Cyathaxonia* sp., *Cryptophyllum caryophyllatum* (de Kon.), *Fasciculophyllum densum* (Carr.), *Permia* aff. *cavernula* Hudson, *Rhopalolasma tachyblastum* Hudson, *R. tachyblastum* cf. *sympecta* Hudson, *Rotiphyllum* cf. *nodosum* (Smyth), *Rylstonia brevisepta* Hudson, *Zaphrentis* sp. cf. *Z. vaughani* Douglas. The exposure in the railway-cutting is the type locality for *Rylstonia brevisepta* Hudson (1942). The fauna is similar to the *Rhopalolasma* fauna described from the Broughton Beds of Butterhaw Quarry (Broughton Anticline) and the Embsay Limestone of the Skipton Anticline. It is considered to be of upper C_2 age.

(i.) Mallardale Shales-with-Limestones.

These beds consist of shales with beds of fine-grained black limestones, with much chert occurring in thin regular bands parallel with the bedding planes. Finely disseminated pyrites is common. A few feet of these beds are exposed in Mallardale Laithe Quarry (A) and in Mallardale Beck ; fossils are rare. These beds are the base of a series which in adjacent areas is seen to be several hundred feet thick.

IV. THE CONISTON COLD AREA.

Exposures north-east of Swinden Moor are not common except near Coniston Cold, where there are several quarries in limestone of C_2 age dipping approximately north-north-east. The dips and arcuate outcrops of the beds exposed here suggest they are near the axis of the Swinden Anticline and that the wide fold they form is the broad pitching nose of the C_2 beds of that anticline. The distance of their outcrop from that of the C_2 beds of the Swinden Moor area and the slight shift to the north-west of the axis of the anticline suggest that they are separated from those beds by a fault with a south-west downthrow. There is evidence south-east of Bank Newton for such a fault, and to the north-west, near Otterburn, it throws Pendleside Sandstone against Mallardale Shales-with-Limestones. Its position across the Swinden Anticline is probably from south-west of Winterly Cobba north-west towards Hellifield. This fault is referred to as the Hellifield Fault.

Near Bell Busk, north of Coniston Cold, there is a further group of exposures in C_2 beds, and again the structure is that of an anticline pitching north-eastwards with the C_2 beds pitching out. The fault, which evidently divides these beds from those of Coniston Cold and for which there is considerable evidence in the areas to the north-west and south-east, is known as the Coniston Cold Fault and occurs in the South Craven Fault System. The main displacement there, however, is at the Gargrave Fault, which shifts the axis of the fold to the north of Bell Busk. The extensive anticline on the upthrow side of this fault is known as the Eshton Anticline. Beds of C_2 age are exposed on its southern flank at Haw Crag and in the adjacent quarries (Hudson, 1927). Beds in this anticline are, however, only generally dealt with in this paper for comparison with the Coniston Cold beds.

(a.) Between the Hellifield and Coniston Cold Faults.

The lowest beds in the area between the Hellifield and Coniston Cold Faults are probably those that outcrop on and around Winterly Cobba—though they are not exposed their position suggests that they may be Thornton Limestones of C_1 age. Around Winterly Cobba there is the wide slack, drained by High Ground Beck, due, it is suggested, to the outcrop of the Nappa Shales-with-Limestone. Exposures on this outcrop in Langber Wood show dark grey bedded limestones with shales. They contain very occasional specimens of *Siphonophyllia cylindrica* group.

The next set of beds was formerly quarried at Warrel, Steeling and Fogger Plantation Quarries (Wilmore, 1912). These beds consist of black thick-bedded limestones containing *S. cylindrica*, *Michelinia megastoma*, *Chonetes* cf. *papilionacea*, *Daviesiella* cf. *comoides*, *Dictyoclostus semireticulatus*, *Plicatifera humerosa* var. *christiani* and *Pustula* sp. The various forms, especially that of *Siphonophyllia*, are those of the Nappa Limestone and it is with that limestone that these beds are correlated. The beds above this horizon have also been quarried, notably at Fogger Rock, Pot Haw Laithe and Dogber Rock. These quarries expose light grey limestone covered by limestone boulder beds. The limestone is sparsely fossiliferous, often porcellanous and with a considerable amount of ' tufa.' It may be well-bedded, or, more usually, have little or no bedding. Contemporaneous breccias are not uncommon. As well as the regional dip there are often steep local dips. The fauna which is one of large brachiopods and molluscs, is of reef phase and of lower C_2 age. The identified fossils from Fogger Rock and Dogber Rock are listed below. Those forms marked by an asterisk were recorded by Thomas (1914).

Brachythyris pinguis (Sowerby)
Chonetes cf. *papilionacea* (Phillips)
Chonetipustula carringtoniana (Davidson)*
Dielasma kingi (de Koninck)
Productus (*Dictyoclostus*) *multispiniferus* (Muir-Wood)
P. (*D.*) *semireticulatus* (Martin)
P. (*Linoproductus*) sp.
P. (*Overtonia*) cf. *fimbriatus* auctt
P. (*Plicatifera*) *humerosus* Sowerby
P. (*P.*) *mesolobus* Phillips*
P. (*Pustula*) *pyxidiformis* de Koninck*
Pugnax sulcatus (Sowerby) and vars.
Spirifer spp.
Syringothyris sp.
Capulus
Euomphalus pentangulatus Sowerby
E. elegans de Koninck.
Straparollus planorbiformis de Koninck
Pericyclus sp.
Cypridellina elongata Jones

The boulder beds which overlie these reef limestones are best seen in Dogber Rock, where they are 40 feet thick and include angular, subangular, and rounded boulders of both reef and bedded limestone with no constant orientation. Some of the large boulders of bedded limestone are upright. Fossils are rare ; some occur in the boulders, some between them. Shales and thin limestones, also showing the effect of movement yet containing large unbroken crinoid stems amid the rock debris, occur above the boulder bed. At Pot Haw Laithe exposures are not large but show bedded limestone with limestone boulders above. At Fogger Rock (Wilmore, 1912) most of the limestone is of reef facies.

The overlying boulder bed, in which most of the boulders are of reef limestone, is best seen in the cutting south of the road. North-west of Fogger there is an old quarry now filled with water but apparently in bedded limestone dipping off the reef limestone surface. It is possible that this limestone is also beneath the boulder bed.

The reef limestones and their associated beds are followed by a thick series of shales, hard calcareous mudstones, thin black limestones often with lamellar chert, and occasional dark grey limestones one or two feet thick. These beds are exposed in Old Rock Quarry and in several small cuttings north-west and south-east of Coniston Cold. They are the Mallardale Shales-with-Limestones of the Swinden Moor district.

(b.) Between the Coniston Cold and Gargrave Faults.

The greater part of this district is occupied by the Mallardale Shales-with-Limestones. They are best seen in Otterburn Beck where, near the Gargrave Fault, they are very much broken and contorted. Exposures in the core of the fold are only of value in the railway cutting at Bell Busk, in the adjacent quarries at Ravenflatt Rock and Town Field Rock, and in Esh Bottom Quarry. The lowest beds may be those outcropping north-west of Coniston Lake, where contorted shales and limestones are poorly exposed in the inflowing beck. These beds are possibly the equivalent of the Nappa Shales-with-Limestones of the Swinden Moor district. It is possible that the Coniston Cold Fault runs farther south than the position shown by the authors (Plate 11) and that the low ground of Coniston Lake is due to such beds.

The beds exposed in Esh Bottom Quarry are now mostly overgrown, and no significant fossils have been collected. The fauna collected by Hind and Wilmore (1912) suggests that the beds may be part of the Nappa Limestone or just below. Reef limestones are nowhere definitely exposed though the bank behind the goods shed at Bell Busk Station exposes light grey limestone which suggests that Town Field Hill may be formed by an outcrop of reef limestone. The lowest beds in the exposures north-west of Bell Busk Station are those in Town Field Rock where about 24 feet of thick-bedded grey limestone with shale partings are exposed. They contain numerous sops of *Syringopora reticulata*, occasional *Pustula pyxidiformis*, *Chonetipustula* cf. *carringtoniana*, both recorded by Thomas (1914), and *Dictyoclostus semireticulatus*. Beds immediately above these are exposed in Ravenflatt Rock, where about 30 feet of very argillaceous limestone with shales are irregularly bedded. They contain *Siphonophyllia* aff. *cylindrica*, *Michelinia megastoma* and occasional *Pustula*. The upper part of these beds, and some slightly higher, is exposed in the railway cutting, and contains *Aulina horsfieldi* (see Smith and Yü, 1943), *Cravenia*, *Koninckophyllum*, *S.* aff. *cylindrica*, *M. megastoma*, and *Pustula pyxidiformis*. Above these beds are boulders of dark grey limestone, mostly bedded.

(c.) North-east of the Gargrave Fault.

The beds at Haw Crag and the adjacent quarries were described by one of us (R.G.S.H.) in 1927. Since then the Eshton Anticline has been mapped in detail. The lowest beds exposed are those near Well Head Quarries, where there are earthy massive bedded limestones with a poor fauna which includes *Pustula nodosa* and *Schuchertella wexfordensis*. The fauna and the position of the beds suggests a correlation with the Thornton Limestone of the Swinden Moor area. To the south-east of these beds is a flat which may be due to the outcropping of Nappa Shales-with-Limestone. The succeeding beds are exposed in Eshton Moor and, across the Aire, at the Crags and Haw Crag. They are about 280 feet thick, and consist mainly of limestone. The general succession is as follows :—

	feet
Crinoidal limestones and shales (Upper and Lower Haw Crag Quarry)	10
Boulder bed with *Palaeosmilia* Shale (Lower Quarry) and *Pustula* Limestone (Upper Quarry)	40
Caninia Limestones (Lower Quarry)	30
Upper Reef Limestone (Upper Quarry and Upper Haw Crag)	50
Lower Reef Limestone, in part bedded and crinoidal (Lower Haw Crag)	30
Grey bedded limestone, partly crinoidal (The Crags)	35
Dark grey limestone with *Siphonophyllia* (The Crags Quarry)	7
Dark grey limestone with *Syringopora* (The Crags)	30
Dark grey earthy limestone with some shale (north-west of The Crags)	50

The limestone with *Siphonophyllia* of The Crags Quarry contains *S. cylindrica*, *Daviesiella* cf. *comoides* and *Rylstonia tenuicolumna* Smyth. The forms of *Siphonophyllia* are the same as those at Warrel Quarry and Swinden Gill Head and the beds containing them are therefore correlated with the Nappa Limestone of Swinden Moor. It was formerly thought (Hudson, 1927) that the *Caninia* Limestones of the Haw Crag Lower Quarry were the equivalent of the Upper Reef Limestone. They are now considered as immediately succeeding that limestone. It was also stated that the *Pustula* Limestone boulders in the Upper Quarry were the equivalent of the *Palaeosmilia* [*Cyathophyllum*] Shales of the Lower Quarry. They are both now considered to be the result of sedimentation during pauses, not necessarily contemporaneous, in the formation of the boulder beds.

The reef limestone and boulder beds are on the same horizons as those of Fogger and Dogber, and it is probable that the *Caninia* beds are on the horizon of the bedded limestones of Bell Busk railway cutting and quarries. Additions to the faunal lists published in 1927 are as follows :—

Lower Reef Limestone :—*Thysanophyllum pseudovermiculare* (M'Coy), *Michelinia megastoma*, *Pustula pyxidiformis*.

Caninia beds :—*Aulina horsfieldi* Smith and Yü, clisiophyllids including *Cravenia* sp. and *Koninckophyllum* spp., *Siphonophyllia* aff. *cylindrica*.

Palaeosmilia [*Cyathophyllum*] Shale :—*Palaeosmilia fornix* Hudson, *Koninckophyllum cyathophylloides* (Vaughan).

Crinoidal limestones and shales (*Chonetes* beds) :—*Permia* aff. *cavernula* Hudson, *Allotropiophyllum* sp. (group of *A. spinosum* de Kon.).

Crinoidal limestone of Upper Quarry :—*Cravenia* cf. *tela* Hudson, *Cravenia* sp., *Koninckophyllum* cf. *tortuosum* (Mich.), *Arachniophyllum* sp. The limestone from which the corals were collected and recorded (Hudson, 1927) as coming from the *Pustula* Limestone, is better considered to be the lower part of the crinoidal limestones and shales of the Upper Quarry.

South-east of Haw Crag there are a number of small cuttings which expose thin-bedded limestones with shales and thin lamellar chert. These beds are the Mallardale Shales-with-Limestones of the Swinden Moor area.

(d.) Correlation with the Succession in the Swinden Moor Area.

The generalised successions in the upper part of the Clitheroe Limestone of the Swinden Anticline and the adjacent part of the Hetton Anticline are as follows :—

CONISTON COLD AND HAW CRAG.

Limestone and shales with a ' Zaphrentid ' fauna (Haw Crag Quarries).
Boulder Beds (Haw Crag Quarries, Dogber).
Bedded Limestones with *Siphonophyllia* (Bell Busk and Haw Crag Quarries).
Reef Limestone (Haw Crag, Fogger and Dogber).
Bedded Limestone with *Siphonophyllia* (Warrel, The Crags).

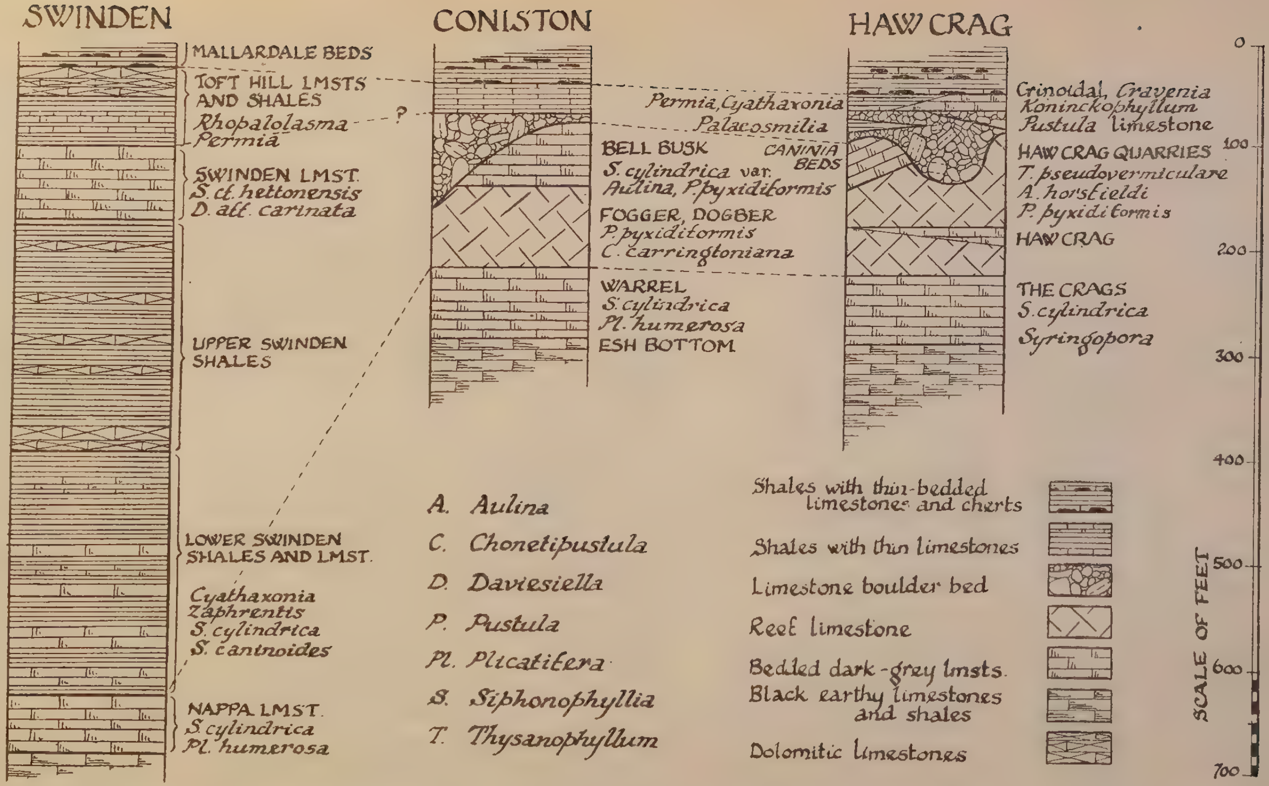

FIG. 21—Diagrammatic vertical sections of the upper part of the Clitheroe Limestone of the Swinden Anticline (Swinden Moor and Coniston Cold areas) and the Eshton Anticline (Haw Crag area). *A. horsfieldi* is found in the *Caninia* limestones of Coniston and not, as the diagram suggests, in the reef limestone.

SWINDEN MOOR.

Limestones and shales with a ' Zaphrentid ' fauna (Toft Hill Beds).
Bedded limestones with *Siphonophyllia* (Swinden Limestone).
Shales and thin limestones (Swinden Shales).
Bedded limestone with *Siphonophyllia* (Nappa Limestone).

The ' Zaphrentid ' faunas of the upper limestones and shales contain in both areas elements such as *Permia cavernula*, *Rhopalolasma tachyblastum* and *Cravenia rhytoides* which link them with the *Rhopalolasma* fauna of the Skipton and Broughton Anticlines (Hudson and Mitchell, 1937 ; Hudson, 1944), and it is suggested that the beds in the Haw Crag and Swinden Moor areas which contain this fauna are on the same horizon. At Haw Crag these deposits rest on boulder beds with an intercalated fauna, the composition of which suggests that the boulder beds should be grouped with them. Though no evidence has been obtained of a break in the succession below the *Rhopalolasma* beds of the Swinden Moor area, boulder beds are associated with that fauna in the Broughton and Skipton anticlines.

The succession below these beds at Coniston Cold and Haw Crag is very different in fauna, lithology and thickness from that of Swinden Moor (Fig. 21). There are, however, faunas which key the two successions together. One of these is the *S. cylindrica* and *P. humerosa* fauna found both in the Nappa Limestone and in bedded limestones of Warrel Quarry and The Crags. These limestones are considered to be on the same horizon. Less certain is the correlation of the *Siphonophyllia* limestones of Bell Busk and Haw Crag with the Swinden Limestone of the Swinden Moor area. The forms of *S.* aff. *cylindrica*, *Daviesiella* and *Zaphrentis konincki* are not quite the same and the Koninckophyllids and *Aulina* of Bell Busk and Haw Crag have not been collected from the Swinden Limestone. Unless, however, there is a considerable break in the Swinden Moor Succession below the Swinden Limestone, the two sets of beds cannot be on very different horizons.

If the above correlations are correct, the beds that occur between the Swinden and Nappa Limestones and between the upper and lower *Siphonophyllia* limestones of Haw Crag (Fig. 21) must be of the same age, and the 450 feet of shale with thin limestones exposed in Swinden Gill are the equivalent of the 150 feet or so of reef limestone exposed at Fogger and Haw Crag, though error in estimating the thickness of either succession may have exaggerated the thickness difference. It is possible that only the lower part of the Swinden Shales is the equivalent of the reef limestone and *Caninia* limestone and that the upper part is the equivalent of the lower boulder beds.

V. CORRELATION OF THE SUCCESSION OF THE SWINDEN ANTICLINE WITH THAT OF THE CLITHEROE ANTICLINE.

A detailed correlation of the Clitheroe Limestone of the Clitheroe and Swinden Anticlines would have much of interest, since it would link a succession that contains a considerable amount of reef limestone with one which is mostly shales and bedded limestone. There is, however, no published account of the details of the succession within the Clitheroe reef limestones, and until such details, both faunal and lithological, are known any correlation with other areas can be only a general one. In the following discussion the succession in the Swinden Anticline is supplemented by that in the Broughton Anticline (Hudson, 1944).

A valuable point of correlation between the two successions is the lithological and faunal similarity between the Newsholme and Coplow reef limestones (Parkinson, 1926) of C_1 age and there is little doubt that these limestones commence at about the same horizon. The relation of their upper beds is, however, uncertain for the rich crinoidal fauna of Coplow has not been seen

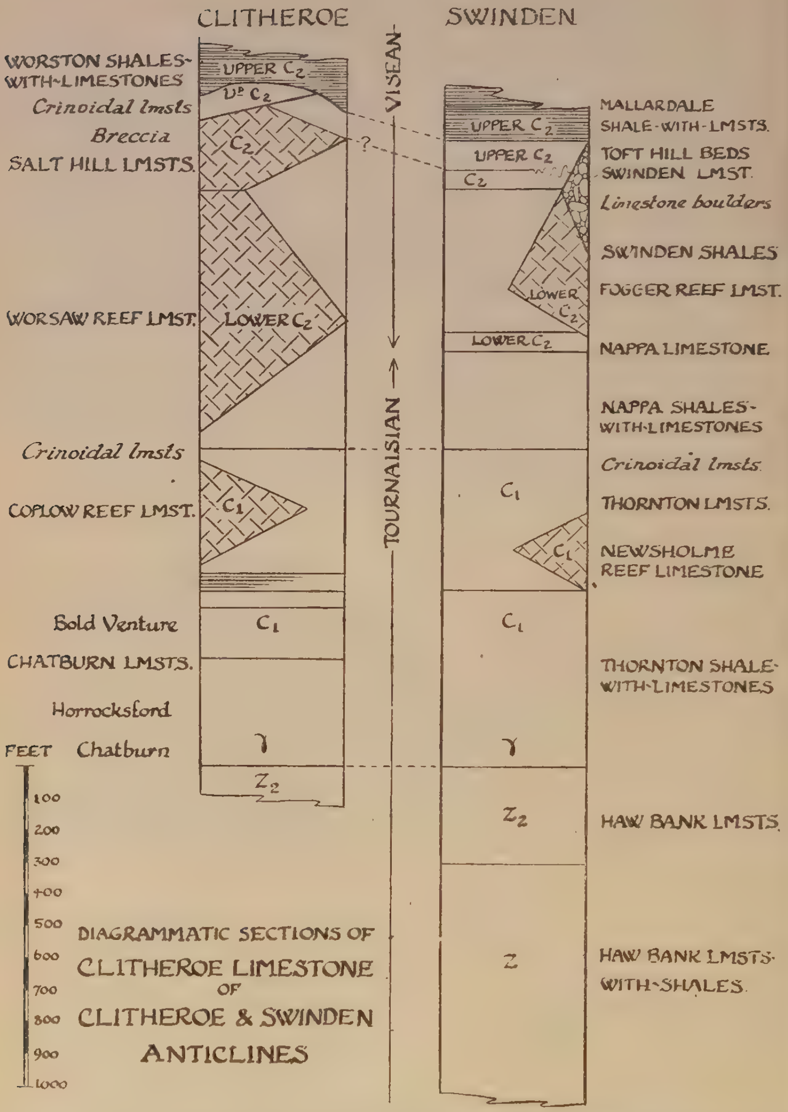

FIG. 22.—Comparative vertical sections of the Clitheroe Limestone of the Clitheroe Anticline (mainly after Parkinson) and the Swinden Anticline. The thicknesses of the Fogger Reef Limestone and the accompanying boulder beds are much exaggerated. It is possible that the Fogger Reef Limestone is the equivalent of the lower part of the Swinden Shales and part of the Nappa Limestone. The division between the Tournaisian and the Viséan may extend to the base of the Nappa Shales.

at Newsholme. The crinoidal fauna of the beds which occur at the base of the Upper Thornton Limestone, and which are well exposed at Clints Delf in the neighbouring Broughton Anticline, is similar to that of Coplow and the two faunas may be on the same horizon.

The successions below these reef limestones in the two anticlines may be correlated with some certainty (Fig. 22.) The 200 feet or so of beds which occur immediately below the Coplow Limestone, and which are well exposed in Bold Venture Quarries, we correlate with the upper part of the Thornton Shales-with-Limestones, though the *Plicatifera humerosa* beds exposed in the upper part of the quarry may be the equivalent of the lowest 50 feet or so of the Thornton Limestones. The limestones with shales exposed in Horrocksford Quarry we correlate with the lower part of the Thornton Shales-with-Limestones (the Skipton Castle Beds) of γ age. Especially noticeable at this horizon is the abundance of *Fasciculophyllum ambiguum* as seen in the quarries at Gledstone Kennels in the Thornton Anticline and in Holywell railway-cutting in the Skipton Anticline. The lowest beds of all are the thin-bedded limestones exposed in the old quarries near Chatburn. These are correlated with the Haw Bank Limestone of Z_2 age. It will be noticed that in the Swinden Anticline there is a considerable thickness of beds older than any in the Clitheroe Anticline, though even in the Swinden Anticline the succession does not extend as far down as in the Gisburn Anticline where there are at least 2,500 feet of beds below the top of the *Zaphrentis* zone.

The beds above the Coplow and Newsholme reef limestones are far from as certainly correlated as those below. At Worsaw in the Clitheroe Anticline the upper part of the Clitheroe Limestone (above the Coplow Limestone) consists of about 1,400 feet of limestone, the lower part of which is as well bedded as the upper part is obscurely bedded (Parkinson, 1927). They are known as the Salt Hill-Worsaw reef limestones and the fauna has been divided by Parkinson into upper (Salt Hill) and lower (lower Worsaw) assemblages, considered to be of upper C_2 and lower C_2 age respectively.

The distinction between the faunas of the C_1 (as Coplow) and the lower C_2 (as lower Worsaw) reef limestones was well brought out, according to the palaeontological knowledge then available, by Demanet (1923) in his comparison of the Four à chaux (C_1) and Sosoye (C_2) Waulsortian limestones of the Maredsous area (see also Paul, 1937, p. 20). The Slaidburn reef limestones, according to Parkinson (1937), contain a typical lower C_2 fauna, and it is with these beds that the Fogger and Haw Crag reef limestones are correlated, mainly on the evidence of various productids. Correlation with the Clitheroe succession is hampered by the lack of a clear line of demarcation between the beds of lower and upper C_2 age. The coral fauna at the top of the Salt Hill beds is similar to that found in the crinoidal limestones and shales of Haw Crag above the boulder beds, the *Clisiophyllum* sp. and *Koninckophyllum clitheroense* of Salt Hill being respectively similar to the *Cravenia* sp. and *Arachniophyllum* sp. of Haw Crag and the beds containing them are probably of similar horizon : the common productids in the reef limestones of Fogger, Haw Crag and Dogber are *Chonetipustula carringtoniana*, *Dictyoclostus multispiniferus*, *Plicatifera mesoloba*, *Pustula interrupta*, *P. pilosa*, and *P. pyxidiformis*, an assemblage which is comparable with the lower Worsaw fauna : *Amplexus coralloides* occurs rarely in both Fogger and lower Worsaw Limestones, but not at all in the Salt Hill limestones : *Pustula ovalis*, *Pugnax mesogonus* and *Spirifer bollandensis*, characteristic brachiopods of the Salt Hill limestone have not been collected from the Fogger limestone below the boulder beds. This limestone, therefore, is below the horizon of the Salt Hill coral and brachiopod faunas, and may be provisionally taken as below all the limestones of Salt Hill ; it is best equated with the lower Worsaw limestone (Fig. 22).

The boulder beds of Fogger and Haw Crag would seem to be on the horizon of the Salt Hill limestone below the crinoidal capping—a suggestion which is borne out by the occurrence of limestone breccias in this bed at Worsaw and Salt Hill. Correlation of the bedded limestones of lower C_2 age cannot be very detailed, but it seems probable that the *Plicatifera humerosa* beds of Peach Quarry in the Clitheroe Anticline (Parkinson, 1927) may be on the same horizon as the Nappa limestones of the Swinden Anticline, which also contain abundant *P. humerosa.*

VI. THE AGE OF THE HAW CRAG AND FOGGER REEF-LIMESTONES.

As the mid-Dinantian earth-movement with its consequent lateral changes in phase and facies took place during *Caninia* times and as the subdivision of the *Caninia* zone has been based on changes in lithology as often as on faunal change, the respective upper and lower limits of the subzones C_1 and C_2 (judged according to faunal change) vary from province to province ; beds in the middle of the zone are allocated to upper C_1 or lower C_2 accordingly as they occur in the Belgian Province or in the South-West or Central Provinces of England. The Haw Crag and Fogger reef limestones occurring between undoubted C_1 and C_2 beds are in this position. They were formerly stated by one of us to be of upper C_1 age (Hudson, 1927). In this paper they are considered to be of lower C_2 age. The reasons for this change are discussed below.[1]

In the original zonal scheme of Vaughan, the *Syringothyris* zone (C), now called the *Caninia* zone, was separated from the succeeding *Seminula* zone by a passage fauna to which the zonal index δ was given. The fauna was stated to be characterised by the maximum occurrence of *Cyathophyllum* [=*Palaeosmilia*][2] ϕ and *Productus giganteus* auctt. [?=*Chonetes carinata* group]. The zone was not subdivided, but later, apparently first by Sibly, C_1 and C_2 were instituted, the division between them corresponding with a boundary in the lithological succession as developed in the Avon section, the *laminosa*-dolomite and the *Caninia* oolite being placed in C_1 and the *Caninia*-dolomite in C_2. When a faunal diagnosis of these two subzones was subsequently attempted it was based on the faunas of the *Caninia* zone in the Mendips, since in the Avon section the *Caninia*-oolite and *Caninia*-dolomite are poorly fossiliferous. Later various index fossils were adopted for the C_1 and C_2 subzones, though none seems to have gained universal acceptance, the most commonly used being *Cyathophyllum* ϕ for C_2 and *Caninia cylindrica* mut. γ for C_1. Most authors, however, omitted subzonal index fossils for the *Caninia* zone. In 1911, Vaughan divided C_2 into upper and lower faunas, the former containing forms which he considered were in general characteristic of the Viséan. In 1915 he retained his C_1 and lower C_2 divisions, but united upper C_2 with S_1 and reintroduced the zonal term δ for this new division, which thus included his original δ and S_1 faunas. The lower C_2 fauna was stated to be marked by the establishment of *Cyathophyllum* [=*Palaeosmilia*] ϕ, *Productus sublaevis* [=*Plicatifera humerosa*] and *Seminula* [=*Composita*] and by the incoming of *Chonetes destinezi.* Later workers in the South-West Province have not used Vaughan's divisions, lower C_2 and δ, but have been content to divide the middle Dinantian into C_1 and C_2S_1 zones, the division between them being the top of the *Caninia*-oolite, with the upper zone extending to the base of S_2.

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[1] In this and the following section (VII) references have not been given to the papers in which the faunas mentioned are described or the breaks in the sequence discussed, since such papers are generally known to those interested in Carboniferous stratigraphy and a complete list would be very lengthy.

[2] Until the lower and middle Viséan forms of *Palaeosmilia* are clearly distinguished, and field evidence leaves no doubt that they are distinct, the name *Palaeosmilia* ϕ is retained to denote the C_2 forms.

In other provinces, however, it has been possible to distinguish between C_2 and S_1 faunas, commonly by the occurrence of *Lithostrotion* in S_1, and to recognize distinct and successive faunas in the C_2 zone. In the Central Province an upper and a lower fauna, both of various phases, can be recognised in the upper part of the *Caninia* zone. In the Bowland-Craven Lowland area, beds containing the upper fauna include the Hetton Limestones with *Siphonophyllia hettonensis* and the succeeding beds with *Chonetes carinata*; the Airton Limestones with *Airtonia* and *Daviesiella notata* and the succeeding reef limestones with *Palaeosmilia* ϕ; the boulder beds of Fogger and Haw Crag and the succeeding shales and limestones with *Arachniophyllum*, *Cravenia rhytoides* and *Palaeosmilia* ϕ, the Swinden Limestone with *S.* aff. *hettonensis* and the succeeding shales with *Rhopalolasma*; the upper reef limestones of Salt Hill with *Spirifer bollandensis* and the succeeding crinoidal beds with *Koninckophyllum clitheroense*; and the Withgill Limestone with *Corwenia vaga*. In the Dublin area, beds with faunas of this age are the Lane Conglomerate and the upper part of the Rush Conglomerate and the beds above. In the southern part of the Central Province they include the *Spirifer bollandensis* limestones of Dove Dale, Derbyshire, and the *Chonetes destinezi* and *Cravenia rhytoides* beds of Breedon, Leicestershire. These beds occur below the incoming of *Lithostrotion* and their faunas are those generally accepted as of upper C_2 age—that they can usually be divided into an upper and lower fauna (upper C_2 and δ as originally defined) does not affect the argument put forward in this section of the paper and has not been discussed.

The lower of the two faunas in the upper part of the *Caninia* zone is less surely placed in the zonal scheme and has been variously attributed to lower C_2 or upper C_1. In the Bowland-Craven Lowlands, beds containing this lower fauna include the reef limestone and *Caninia* limestones of Fogger and Haw Crag with *Pericyclus*, *Thysanophyllum pseudovermiculare* and *Aulina horsfieldi*; the Nappa Limestone and Swinden Shale with *Plicatifera humerosa* and *Siphonophyllia cylindrica* cf. mut. γ, the bedded limestones of Bell Busk with *S. cylindrica* cf. mut. γ, and *A. horsfieldi*, the bedded limestones of Peach Quarry, Clitheroe, with *P. humerosa*, and the reef limestones of Slaidburn and lower Worsaw with *Chonetipustula carringtoniana* and *Dictyclostus multispiniferus*. In the Dublin area the beds with this fauna probably include the lower part of the Rush Conglomerate and the Lane Limestone with *P. humerosa*, while in the southern part of the Craven Lowlands they include the reef limestones of Dovedale, the Caldon Low Limestones of North Staffordshire and the dolomitic limestones of Breedon, Leicestershire, all with *P. humerosa*. Most of these beds have a considerable thickness of C_1 beds below them and C_2 beds above them, so the only question is their allocation to upper C_1 or lower C_2. Most of them contain early forms of *Koninckophyllum*, *Rylstonia* and *Palaeosmilia* ϕ, and the general censensus of opinion is that they are of lower C_2 age.

The upper and lower C_2 faunas of the Central Province can be paralleled in the North-West Province. There the lower fauna is found in the oolitic limestones with *Thysanophyllum pseudovermiculare* and *Palaeosmilia* ϕ at their base and the Brownber Pebble beds with *Syringothyris cuspidata* at their top. The upper fauna is found in the *Spirifer furcatus* band with *Z. konincki*, *Carcinophyllum*, *Carruthersella* and *Koninckophyllum*, and the succeeding *Michelinia grandis* beds with *Camorophoria isorhyncha* and *Chonetes carinata*. These lower and upper faunas are usually accepted as of lower and upper C_2 age. The upper fauna is also found resting on, or is the equivalent of, the basement conglomerates of the Isle of Man and the Ingleborough area.

If these lower and upper C_2 faunas of the Midlands and the North of England are compared with the faunal succession in the *Caninia* zone in France, Belgium and Germany, there is a marked similarity. In Belgium the upper fauna in the Dinant area is found in the Marbre noir de Dinant with *Chonetes destinezi* and probably in the overlying Dolomie de Sovet with *Daviesiella.* The lower fauna is found in the Dinant area in the Waulsortian reef limestones of Sosoye with *P. humerosa*, *Palaeosmilia* ϕ, and other corals, while in the Namur area it is found in the oolitic limestones or crinoidal dolomites with *P. humerosa*, *Palaeosmilia* ϕ and *Syringopora favositoides.* It is probable, however, that the lower part of the Marbre noir is of lower C_2 age and the upper part of the Sosoye reef limestones of upper C_2 age. Rocks of similar facies and with the same faunas occur in the north and north-west of France.

In Germany the lower fauna and probably part of the upper is represented in the Aachen area by the *Vaughanites*-oolite with *Syringopora flabelliformis* and at Ratingen and elsewhere in Westphalia by the transgressive Erdbach Limestone and the overlying crinoidal and brecciated limestones with *P. humerosa, Pericyclus*, *Merocanites applanatus* and *M. holzapfeli.* The Zadelsdorf beds with *Muensteroceras euryomphalum* also probably contain the upper fauna. These faunas are universally recognised as of C_2 age.

In the South-West Province there is no satisfactory faunal division of C_2 in spite of the attempts at such a division in the Mendip, Gower and Cardiff areas. This is apparently due to the absence of a diagnostic lower C_2 fauna. In Gower and the Vale of Glamorgan, for instance, the C_2 beds contain *Chonetes destinezi*, *Muensteroceras euryomphalum*, *Cravenia lamellata*, *Palaeosmilia* ϕ, *Siphonophyllia cylindrica* group and *Michelinia grandis*, a fauna equivalent to the lower part of the upper C_2 fauna discussed above. No lower C_2 fauna is recorded from the beds below. A generalized succession in the S.W. Province of the upper part of the *Caninia* zone above the *laminosa*-dolomite is—the *Caninia*-oolite at the base, then often a break in the succession, and finally the *Caninia*-dolomite or crinoidal limestones. This is comparable to the familiar lithological succession of the beds with the lower and upper C_2 faunas discussed above, and it seems possible that the *Caninia*-oolite of the S.W. Province is the equivalent of the *humerosa*-oolite of France, Belgium and Germany, and that the various facies of the *Caninia* zone are more constant and more valuable as an aid to correlation than Vaughan (1915) would allow. This suggested correlation is borne out by recent work of George and others who record *Palaeosmilia* ϕ, *Koninckophyllum praecursor*, *Cravenia* sp., and *Pericyclus kochi*, a characteristic goniatite of the Erdbach Limestone, from the *Caninia*-oolite of Gower and Glamorgan. The *Caninia*-oolite has long been considered to be of C_1 age, partly, apparently, because of the sharp break in the Avon section between it and the succeeding *Caninia*-dolomite of C_2 age, and partly because of a mistaken correlation with the beds of the Mendip succession. If the above correlation of the *Caninia*-oolite with the *humerosa*-oolite is correct then, it is suggested, the *Caninia*-oolite should be transferred to the C_2 zone, and not the *humerosa*-oolite and the beds correlated with it to the C_1 zone.

VII. THE MID-DINANTIAN EARTH-MOVEMENT AND THE DIVISION BETWEEN THE TOURNAISIAN AND THE VISÉAN.

That the mid-Dinantian boulder beds of considerable thickness are a localised phenomenon connected with the lower C_2 reef limestones is shown by their occurrence with these limestones and nowhere else: that the crustal movement which initiated these boulder beds had a much wider extent than the area of those limestones is shown by the unconformity in the south-east of the Craven Lowlands, which resulted in the overstep of the *Rhopalolasma* beds of upper C_2 age on to beds as low as γC_1 (Hudson and Mitchell, 1937; Hudson, 1944). It is proposed to defer any consideration of the formation of these lower C_2 reef limestones and the associated boulder beds until the succession in the Airton Anticline has been described, as there the passage beds from the reef limestones northwards are exposed. Nevertheless, it is important that there should be a realisation of the contemporaneity of the widespread effects of this mid-Dinantian movement, since they are a factor both in correlation and in the fixing of the zonal boundaries.

In the Bowland-Craven Lowland district of the Central Province the effects of the mid-Dinantian movement have been recognised in many areas. In the Slaidburn area Parkinson has suggested a break in the succession above the lower C_2 reef limestones and at Thornley he has described limestone boulder beds of C_2 age. In the Clitheroe area a break in the succession above the Clitheroe Limestone and below the Worston Shales has been considered to be the major effect of the mid-Dinantian movement; we suggest, on faunal evidence, that the horizon of that movement is below the upper limestone of Salt Hill at or about the breccias that occur there. In the Swinden-Skipton area the boulder beds of Fogger and Haw Crag and the overstep of the Embsay Limestone on to γC_1 beds are also the result of the earth-movement. To the west the Rush and Lane conglomerates of the Dublin area are mainly of upper C_2, age while to the north, on the Pennine massif, the basement conglomerates of the Ingleborough area of late C_2 age show evidence of the erosion of slightly earlier beds. The Brownber pebble bed is evidence that the movement extended into the North-west Province. In the southern part of the Central Province in West Derbyshire and North Staffordshire the mid-Dinantian unconformity is of wide extent, varying in its depth according to its position on crest or trough of the contemporaneous folding. The pebble beds of Caldon Low are of the age of this movement and the unconformity also occurs at Lilleshall. On the southern margin of this province at Breedon, Leicestershire, the unconformity of beds with *Chonetes destinezi* on those with *Plicatifera humerosa* is marked by pebble beds. In most cases these manifestations of the crustal movement can be shown to occur between beds of lower and upper C_2 age and are themselves usually of upper C_2 age, though in certain cases such as the Rush Conglomerate they may commence at the base of C_2. In Belgium, limestone breccias are common above the *humerosa* limestones and below upper C_2 beds, and in Westphalia the transgression of the Erdbach limestone across various earlier beds (Paul, 1937) was used as the typical example of Nassauian earth-movement. In the S.W. Province the maximum shallowing, and in some cases a slight break, occurs between the *Caninia*-oolite (lower C_2 ; C_1 auctt.) and the overlying *Caninia* dolomites and crinoidal limestones (upper C_2), an occurrence which supports the allocation of the *Caninia*-oolites to the lower C_2 zone.

Thus, it is argued, the Nassauian orogeny commenced with variable shallowing, which resulted in oolitic limestones such as the *Caninia* and *humerosa*-oolites or reef limestones such as those of Sosoye, Fogger and Slaidburn, or the equivalent bedded limestones such as the Calcaire violacé or the lower part of the Marbre noir of Belgium: it then culminated in the movement which resulted, locally, in boulder beds, limestone breccias and pebble beds or, more widespread, in deep erosion: it was finally followed by the extensive upper C_2 transgression.

It is not very important where the division between the Tournaisian and the Viséan is placed provided its position in the succession is constant. For many years the division in Belgium has been taken between the Assise de Dinant and the Assise de Celles, that is, between the *humerosa*-oolite or the Sosoye reef-limestones and the Calcaire de Vaux, Calcaire de Paire, the dolomie tournaisienne (*laminosa*-dolomite) or the normal Waulsortian reef-limestones, namely, between C_2 and C_1 (Mailleux and Demanet, 1930). The use of a similar division is the practice in Westphalia (Paul, 1937) and France. Vaughan adopted the division, but in the opinion of the authors incorrectly placed it in the succession of the S.W. Province, except, perhaps, in the Mendip succession. His division was not, however, generally adopted. If, as suggested above, the climax of the Nassauian orogeny took place at the same time over north-west Europe, then the horizon of the movement might be made the division between the Tournaisian and Viséan. This suggestion was made by Dixon in 1911 and has been generally accepted in the S.W. Province and also in certain areas in the Central Province. Thus, in Great Britain the top of the Tournaisian is taken at the top of the *humerosa* beds (or an equivalent horizon at the top of lower C_2), whereas in Belgium it is taken at the base of those beds (or an equivalent horizon at the base of C_2). Besides being contrary to that in Belgium, the English practice has the disadvantage that the division occurs in the middle of the C_2 zone. The authors, therefore, propose to abandon it and to make the base of C_2, as in Belgium, the division between the Tournaisian and Viséan. In the Swinden area the base of the Nappa Limestone is thus this division.

VIII. SUMMARY.

The Swinden Anticline in the centre of the Craven Lowlands has been mapped on the scale of six inches to the mile and a succession, about 3,000 feet thick, is established as mainly Clitheroe Limestone and of Z to upper C_2 age. The beds are mostly sparsely fossiliferous, dark grey, bedded limestones with a varying amount of shale. Reef limestones of C_1 age were once quarried at Newsholme and others, with boulder beds above them, are exposed at Dogber, Fogger and Haw Crag. Their age and that of their equivalents in England, Belgium, and Germany is discussed and determined as lower C_2. It is suggested that the *Caninia*-oolite of the S.W. Province is also of this age. The boulder beds are considered to be the result of mid-Dinantian orogeny of upper C_2 age and are correlated with other effects of that movement in the north and midlands of England. The division between Tournaisian and Viséan is taken at the point where this movement is *first* made evident by its effect on the sediments, and this entails the abandonment of the customary English line of division. It is, instead, placed at the base of C_2, thus conforming with the practice in Belgium, France and Germany. Correlation of the Swinden succession is made with that of Clitheroe, thus linking a facies mainly reef limestone with one mainly limestone and shale.

Thelma Fox kindly lettered the diagrams and maps of this paper, and G. Cotton corrected the proofs. To both, the authors record their thanks.

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EXPLANATION OF PLATES 10 AND 11.

PLATE 10.

Geological map of the Swinden Moor area showing part of the Swinden Anticline. The greater part of the map is of the outcrop of Clitheroe Limestone, which includes all the beds from the Haw Bank to the Toft Hill Beds. Not all parts of the boundary lines of the Newsholme and Flambers Reef Limestone have equal value. In general the boundary line is an expression of a topographical feature, more or less evident, which can be variously interpreted. Laterally it is not necessarily the limit of the reef limestone.

PLATE 11.

Geological map of the Coniston Cold area showing the faulted pitching end of the Swinden Anticline and, across the Gargrave Fault, the open end of the Eshton Anticline. The unlined area is the outcrop of the Clitheroe Limestone, the lined area the outcrop of the Mallardale Shales-with-Limestone. No attempt has been made to show the boundaries of the reef limestone which is exposed at Fogger, Dogber, ? Bell Busk and Haw Crag.

THE APPLICATION OF TILT TO A FOLD.

By G. D. HOBSON, Ph.D., A.R.S.M., D.I.C.

[*Received 4th February,* 1944.]
[*Read in abstract, 2nd December,* 1944.]

FROM a structural point of view the ultimate primary objective in geological mapping is the delineation of the form of one or more horizons by means of stratum contours. The extent to which this can be achieved, and the degree of accuracy attainable, will vary with the geology of the area, and with the amount of surface and subsurface data available. When satisfactory stratum contour maps can be compiled it becomes possible to work out in some measure details of the movements by which the beds attained their present spatial distribution. Having regard to the length of time spent in the mapping of an area, it seems well worth while to spend a few hours on constructional work, even though it may be tedious, if it provides more reliable information on the mechanism of the movements than does the application of certain 'rules,' which are often of limited value and can be misleading.

The contructional methods to be described deal only with tilting, and in particular with tilting associated with faulting, for this seems to be one of the few cases in which there is a possibility of measuring the relative tilt between two parts of the earth's crust. The methods are suitable for checking the mechanics of the mapped structure, and can also be employed in the construction of problem maps by the application of a known set of movements to a hypothetical structure. They are strictly accurate, and naturally can be applied to any degree of refinement. However, if the contour systems are not satisfactorily defined, there is nothing to be gained from the rigid application of these methods, since the uncertainty in the original data will confer similar uncertainty on the results, even though accurate constructional methods may be applied.

Tilt about a horizontal axis.

If a structure is cut by a vertical fault plane, and the two fault blocks have undergone relative scissor movement, i.e., one block has been tilted relative to the other, with or without any other component of movement, the stratum contours of the two blocks may appear to show that one block has suffered a different degree of folding from the other. It is therefore desirable, from the point of view of interpretation, to test the validity of this indication. If there has been no difference in folding on the two sides of the fault plane, then the cross-sections shown on the two fault faces will be identical in shape, although displaced. Hence, if the profile of a given bed is drawn as seen on each side of the fault plane, the net movement on the fault plane will be revealed, when the folding is the same on both sides ; when there has been a difference in the folding it will be shown by the two profiles, and there will also be evidence of the nature of the fault movement, but the latter cannot be determined fully in the absence of some feature which can be correlated on the two fault faces.

The profiles of a bed on the two sides of the fault plane can readily be constructed from the stratum contours. If the profiles are identical in shape, the movement necessary to superimpose them gives the net relative movement of the two fault blocks. (In Fig. 23*b* a tilt of 7° has taken place about the horizontal axis through P_A. The two profiles are drawn on AA′, the fault plane in Fig. 23*a*. The mapped contours of Fig. 23*a* are shown by full lines. The two profiles are identical in form and can be superimposed by rotating through 7° about P_A.)

In order to restore the structure shown in full lines in Fig. 23*a* to its original position, assuming that only the southern fault block has moved, one of the

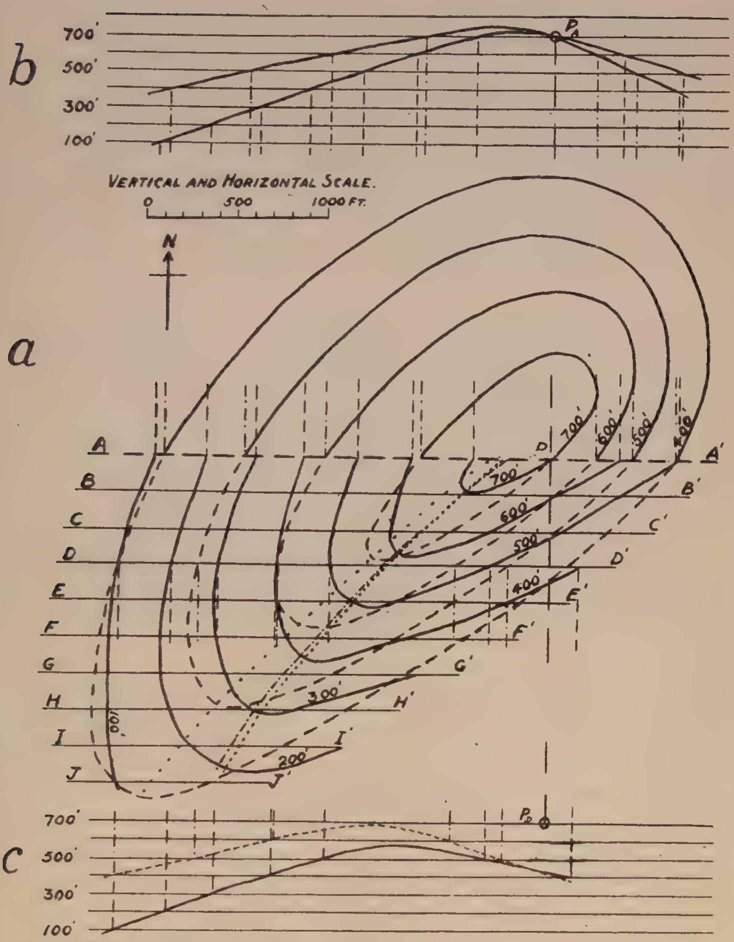

FIG. 23.—Construction for applying tilt about a horizontal axis.

methods of construction which can be used is as follows :—The axis of tilt must be at right-angles to the fault plane, and horizontal, since the fault plane is vertical and the profile the same on the two sides of the fault plane. From the two profiles drawn on the fault plane it is apparent that the axis is at P_A at a height of 700ft.[1] At right-angles to the axis of tilt, and therefore parallel to the fault trace AA′, draw a series of parallel lines—BB′, CC′, DD′, etc.—to divide the southern fault block by the minimum number of planes, profiles on which will adequately define the entire structure. Outside the contoured area draw a series of lines parallel to AA′ (Fig. 23*c*), and spaced at the vertical contour interval (to scale). Number the last series of parallel lines to correspond with the contours on the southern fault block, and then construct the profile of the structure as seen on one of the dividing planes, e.g. DD′, in the usual manner. Project the axis of tilt on to Fig. 23*c*, and mark it (P_D). Trace the profile and the point P_D, and, keeping the axis of tilt on the tracing superimposed on P_D, rotate the tracing paper about P_D, through the angle of tilt (7°) in the appropriate direction. Holding the tracing paper carefully in this new position, prick through the points where the traced profile intersects the series of parallel lines on which the profile along DD′ was drawn. Project these pricked points back on to the line DD′. and label them according to the height which they represent. Treat the other lines of section, BB′, CC′, etc., similarly, and then connect together the spot-levels showing the same height, in order to give the stratum contours (broken-line contours on Fig. 23*a*) of the southern fault block before it was moved relative to the other fault block.

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[1] It should be noted that the point at which the two profiles intersect is not necessarily the axis of tilt. Each case must be considered on its merits, and the movement necessary to superimpose the two profiles must be ascertained by trial.

Tilting about an inclined axis.

When a scissor movement takes place on a non-vertical fault plane, the relative movement of the fault blocks is equivalent to the tilting of one of the blocks about an inclined axis, for the axis of tilt must be normal to the fault plane, unless there is distortion of one or both of the fault blocks in the fault movement. The determination of the amount and direction of the net fault movement, and the testing for different degrees of folding on the two sides of the fault plane, are again made by comparing the form and position of the profiles of a given horizon as seen on the *inclined fault plane*.

In Fig. 24*a* the full lines represent the stratum contours on the two fault blocks. Since the fault is not vertical the lines in which the faulted contoured surface end on the fault plane are not straight in plan, but curved as shown. These lines are defined by the points at which each stratum contour meets the corresponding fault plane contour.

In order to draw the profiles on the inclined fault plane, a series of equally-spaced lines are drawn parallel to the strike of the fault plane (Fig. 24*c*), the spacing being equal to $a . \operatorname{cosec} \theta$, where a is the vertical contour interval (to scale) and θ the dip of the fault plane. The lines are numbered to correspond with the contour levels. Next the point at which each stratum contour meets the fault plane is projected on to the appropriate line on (Fig. 24*c*), and then the projected points are connected together to give the two profiles of the broken ends of the stratum. In Fig. 24*c* the two profiles are identical in form, and they can be superimposed by rotation through 7° about the point P_N. Again, the pivotal point P_N need not be on either profile, much less at the point of intersection of the two profiles, if they happen to intersect.

In order to tilt a structure about an inclined axis, e.g. to restore the southern block of Fig. 24*a* to its original position relative to the northern block, the following method is applicable :—Let the inclined axis of tilt intersect the fault plane at the point P (Fig. 25*a*). Then PA will be the plan view of the axis of tilt, which, being normal to the fault plane, will run at right-angles to the fault strike on the plan. The fault plane dips at 60°, and is defined by contours as in Fig. 24*a*. P is at a height of 700ft. Suppose that it is desired to apply the tilt to a point X which lies on the 500ft. stratum contour. Draw an elevation showing the fault plane edge-on (Fig. 25*b*), with a series of parallel lines spaced at intervals equal to the vertical contour interval to scale. These parallel lines represent the edge-on view of horizontal planes at the contour levels. Project X on to the elevation where it will be represented by X′ at the 500ft. level. Since the axis of tilt is normal to the fault plane it will be at right-angles to the trace of the fault plane on the elevation, and when the point X undergoes rotation about the axis of tilt it will move in a plane parallel to the fault plane, i.e., on the elevation it will move along a line (DX′ or its extension) parallel to the trace of the fault plane. The rotation must be applied on the fault plane

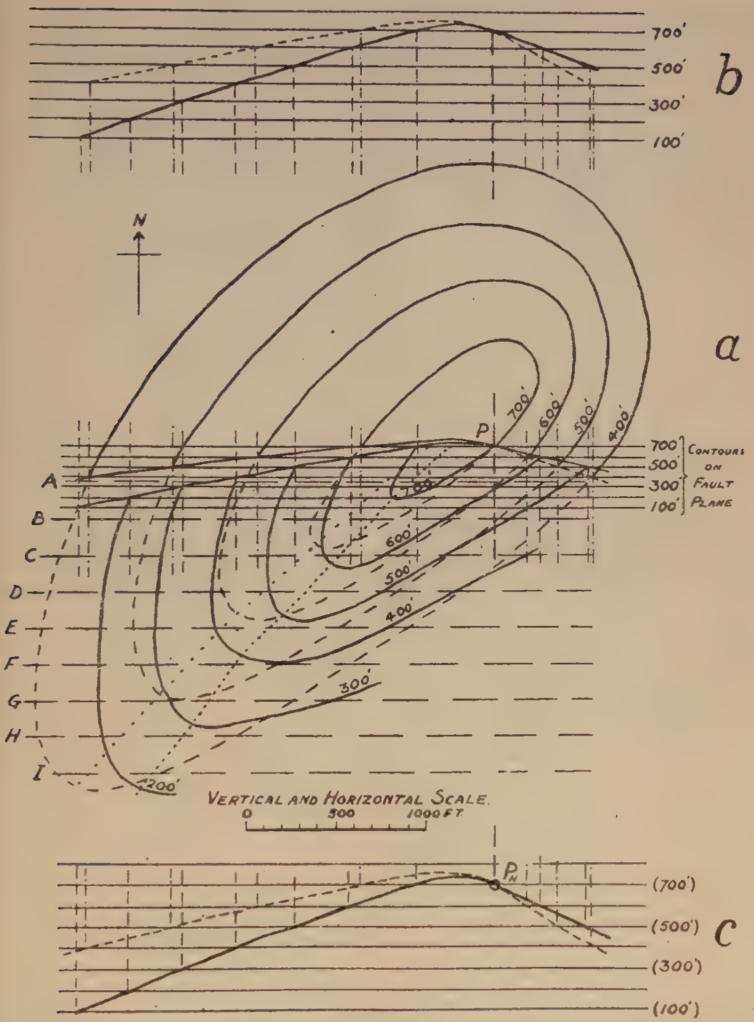

FIG. 24.—Structure showing effects of tilt about an inclined axis.

(or on planes parallel to it), and therefore the position of X relative to the pivotal point must be located by projection on to a ' plan ' that is parallel to the fault plane. Extend the line representing the axis of tilt on the elevation, and from some point on the extension, selected as the pivot, draw a line at right-angles to it (Fig. 25*c*). Project X′ parallel to the axis of tilt (Fig. 25*b*) on to the fault plane projection to give X″ (Fig. 25*c*). The distance of X″ from the line Pivot-B (Fig. 25*c*) is equal to *l*, where *l* is equal to the distance of X from the line PA on the original plan (Fig. 25*a*). X″ is now rotated about the pivot through the desired angle (in this case 7°) to (X″), which is then projected parallel to the axis of tilt (Fig. 25*b*) to give its position—(X′)—on the elevation. As indicated previously (X′) must lie on DX′ or on DX′ produced. (X′) is at a height of

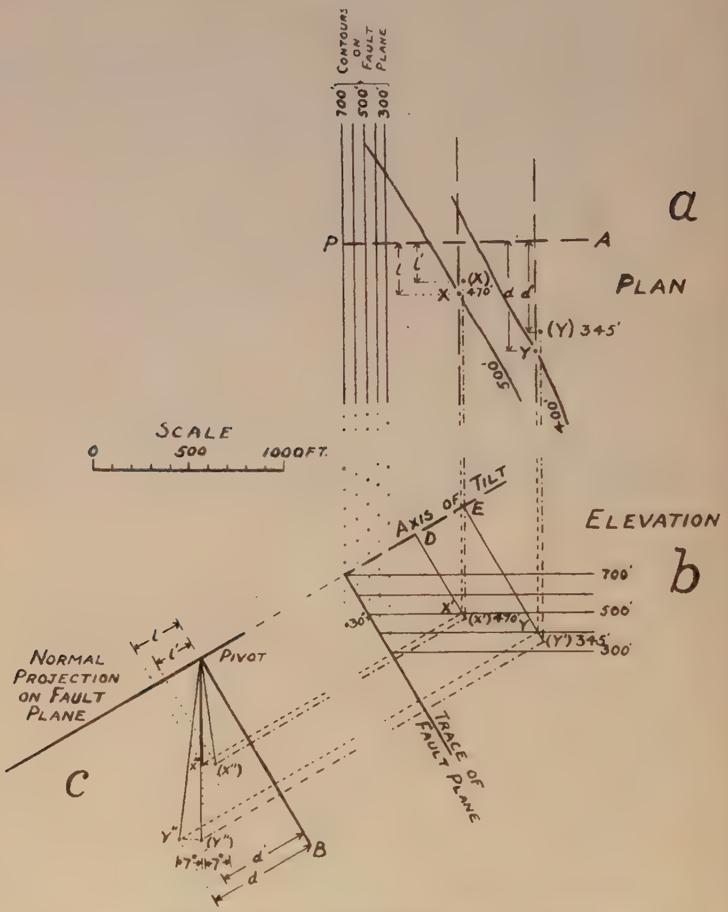

FIG. 25.—Construction for applying tilt about an inclined axis.

470 ft. (X′) is now projected on to the plan (Fig. 25*a*), where it is represented by (X), which is at a distance *l*′ from PA, as shown by the distance of (X″) from the line Pivot-B on Fig. 25*c*. The point (X) is labelled with its height of 470 ft. Figs. 25*a*, 25*b* and 25*c* also show the construction for the application of the same tilt to a point Y on the 400 ft. contour of Fig. 25*a*, and the construction is lettered to conform with the scheme adopted for point X. The construction is carried out in the same manner for a number of points sufficient to define the surface of the stratum after the tilt has been removed. Stratum contours are afterwards interpolated between the series of spot-levels obtained.

The broken-line contours of Fig. 24*a* show the contours of the southern fault block after it has been rotated through an angle of 7° about an inclined axis. The points to which the rotation was applied in the construction were selected at the points of intersection of the parallel lines A, B, C, etc., and the stratum contours (the lines A, B C, etc., are parallel to the fault strike).

Fig. 24*b* shows the profiles of the broken edges of the faulted contoured surface as drawn on a vertical plane parallel to the fault strike. Since the tilt is small and the fault steep, the two profiles are almost identical, and indicate an angle of tilt that is only slightly less than the true value.

Features incidental to tilting.

(a.) *Zones of elimination or of repetition.* On the west side of Fig. 24*a* the scissor faulting has created a zone of elimination and on the east side a zone of repetition of the contoured horizon, i.e., in vertical borings in these zones the contoured horizon respectively would not be met, and would be met twice. The existence and size of these zones depend on the position of the axis of tilt, the form of the structure, the angle of tilt and the inclination of the fault plane. However, scissor faulting is not the only mechanism whereby a zone of elimination and a zone of repetition can be formed along a single fault.

(b.) *Effect of tilting on the crest-line or pitch of a fold.* When a fold is tilted in any but certain special directions, the line on the surface of a given stratum which shows the crest-line or pitch of that stratum will change its plan position, and unless the fold is very sharply crested, this line will not be the crest-line of the fold in the fold's new position, c.f. Challinor. In Figs. 23*a* and 24*a* the plan position of the crest-line of the fold in each of the fold's two positions is shown, in one case by the line of widely-spaced dots, and in the other case by the line of closely-spaced dots. The dot and dash line on Fig. 23*a* shows the plan position to which the line of closely-spaced dots (representing the crest-line of the structure drawn in full-line contours) would move when the fold is tilted to the position in which its contours are shown by the broken line contours (the true crest-line in this latter position is marked by the line of widely-spaced dots). The extent of this migration of the crest-line as a result of tilting will depend on the form of the fold, the amount of tilt, and the angle between the axis of tilt and the original crest-line.

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NOTE ON THE ORIGIN OF ISLAND ARCS.

By A. J. BULL, Ph.D., F.G.S.

[*Received* 21*st January*, 1944.]
[*Read in abstract*, 2*nd December*, 1944.]

ISLAND arcs are a well known geographical feature of the earth's surface. They are arcuate groups of islands, which are generally bowed away from a continental mass. The Kurile Islands, Japan, and the Ryukyu Island bowing out from the Pacific coast have the land-mass of Asia behind them. The Mariannas stand out in the Pacific far from Ásia, but still the concave side faces westward, and there are indications of shallow sea connections. In some cases, however, any relationship to a land-mass is not so obvious. For instance, the arcs of the Aleutian Islands and of the West Indies have not a huge land-mass behind them, but bow outwards from gaps between continents. They all, however, possess the same main characteristics.

SOME CHARACTERISTICS OF ISLAND ARCS.

A feature of some arcs is that the row of islands has on its convex side a deep part of the ocean. For example, in front of the Sunda Arc is a narrow deep parallel to the islands. The southern part of the Mariannas is fronted by a nearly parallel deep, while the Tuscadora Deep to the east of Japan is among the deepest known.

Hobbs [4*] from his study of arcs believed that they rise from the sea as islands with quaquaversal outward dips ; such islands are the higher parts of an undulating anticlinal ridge, and as this emerges so the islands join. Hobbs also considers that the curvature of the arc increases with age. That the islands have frequently risen is demonstrated by the presence of raised reefs well above the present sea level. In some of the larger islands the rise has been considerable, on Timor for example the old reefs occur as high as 1300m. Curaçao, in a subsidiary arc of the Lesser Antillean Arc, is a good example of the domed anticline of a rising island, for Verbeek has observed that the limestone of recent reefs has been raised from the sea and bent into a dome. Hobbs states [**4**, p. 256] that the anticlinal structure occurs in recent reefs on the island, whose surfaces show that they have never been under load from superincumbent rocks, " and their folding must therefore have occurred not within a zone of flow deep below the surface, but where they now are."

In some cases the arc is double, when the outer arc usually consists of Tertiary terrigenous deposits, while the inner arc is sometimes built of older rocks. The Kurile Arc is double, but most of the outer islands are submerged. Barrier reefs or lines of atolls, which may occur inside (Mariannas) or outside (Pelews) the arc, are probably indicative of the flanks of an anticline subsiding as the folding proceeds.

Hobbs [**4**] regards the front middle section as being particularly unstable, for it is often partly submerged or missing, and is the seat of earthquakes. The outer line of islands in the Sunda Arc is grouped at the two ends, the Mentawei Islands off Sumatra and in the east there are Sumba, Savu, Timor, etc., but in the middle of the arc off Java there are no islands but a submarine ridge.

Volcanoes are of frequent occurrence in island arcs, but they are always on the inner concave side. In the Sunda Arc the volcanoes are thickly dotted along the inner curve in a line which may be double in places. The Lesser Antillean Arc has small islands, especially on the northern flank, consisting largely of

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* For List of References see p. 226.

Tertiary clastic tuffs, and these have been invaded by a wide range of igneous rocks, which are regarded as having a relatively deep-seated origin [4]. The lavas of the Andaman Islands are andesitic. These are but a few examples of a feature that is constantly present in island arcs, and has been regarded as the most persistent and lasting of their characteristics.

Where the row of islands has a smooth curve, the structure would appear to be comparatively simple. In the Kuriles, which have only a small curvature, the elongated islands of the inner arc have a slight echelon arrangement of their structural lines; this has been described by Tokuda [8], who is not quite clear as to the nature of the structures; it may, however, be assumed from the context that his lines indicate simple anticlinal folding. These lines are slightly stepped landwards from the most easterly line, and their overlaps increase towards the ends of the arc. The Ryukyu Arc between Formosa and Southern Japan has again but small curvature through most of its length, but at its ends near the flanking land-masses there are sets of overlapping echelon folds; the whole arrangement is in conformity with the idea that the arc has been dragged outwards from the land, with the two flanking land-masses as obstacles to the movement. Fujiwhara [2] states that the volcanic ranges in Japan have an echelon arrangement.

The Mariannas stand well out in the Pacific, but they are regarded by Tokuda [8] as the middle portion of a gigantic arc with echelon structures on the wings; this idea is supported by the fact that a shallow water part of the ocean extends northwards to Japan and the statement that the directions of the structural lines in Ulithi, Yap, Palau, Sonal, and Halmahera to the south-west are in accord.

SUGGESTED MODES OF ORIGIN.

Contradictory views have been expressed as to the causes of island arcs. Suess has postulated an orogenic force directed outwards from inside the arcs, without any precise indication as to how such a force might arise and be transmitted. Hobbs [3] and others have expressed the opinion that these island festoons were produced by a force in the opposite direction. According to Hobbs, the ocean floor is presumed to sink and to press on the continents, forcing the outer parts into folds which overturn towards the ocean, because the force is applied below the surface of the crust. That the floor of the Pacific has sunk in stages during Tertiary times with the result that the general sea-level has been lowered is most probable, but why this should produce pressure on the continents is not clear. Prof. Holmes [5] on the other hand cites the echelon structure of island arcs as evidence of sub-crustal currents. Tokuda [8] favours a force from inside and has described illustrative experiments, in which a sheet of soft paper is laid on a sheet of glass with rice paste, and the surface of the paper is moved locally by a finger pressed on it; in this way patterns of anticlinal folds en echelon were produced.

It may be remarked with regard to these experiments that when one presses on a sheet of paper supported on a rigid base, it represents an area of the earth's crust being held firmly by some unknown force applied from above the crust, and then this area being moved in its own plane to compress adjacent portions of the crust. Among all the forces that have been cited as possible agents of earth movement, it is not clear that any can act in this manner. This criticism also applies to published experiments by J. S. Lee [7] and Hobbs [4, p. 261]. In Tokuda's experiments the maximum compressional stress occurs just behind the folds at the margin of the area being pushed forward by the finger, but this is exactly the place where the volcanoes are situated, and the crust is presumably in tension.

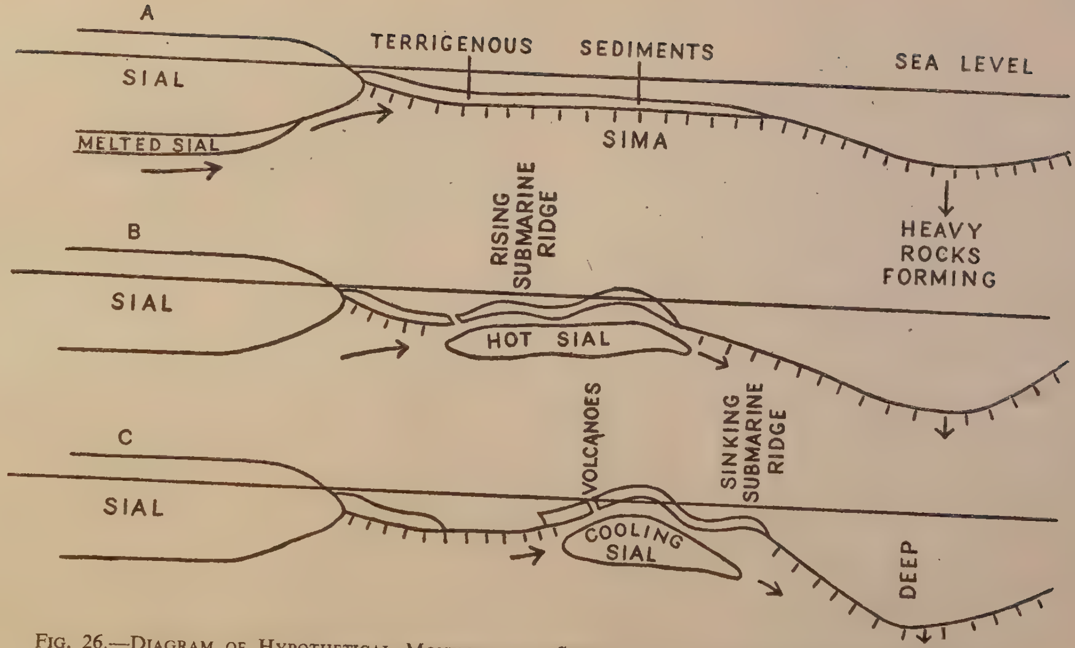

FIG. 26.—DIAGRAM OF HYPOTHETICAL MOVEMENTS OF SUB-CRUSTAL MATERIAL PRODUCING ISLAND ARCS.

HYPOTHESIS.

Some conceptions in the publications of Prof. Joly [**6**] and Prof. Holmes [**5** and other papers] provide a basis for an explanation of the formation of island arcs. These are (a) that the sub-crustal material under the continents becomes hotter than under the oceans, not only because the more acid rocks generally contain more radium and potassium than basic rocks, but also because the thick sial masses of the continents blanket the heat given out by the radioactive elements ; (b) that the deeps of the oceans are produced by the sinking of material of relatively high density ; and (c) these conditions may give rise to convection currents. No convective movement could take place until the conditions were sufficiently unstable and the sub-crustal material was fluid enough. While much of the moving material would be the more fluid basic sima, it must be assumed that in the case of a stream coming up from under a continent it includes some fluid or plastic sial, for as the current moves outward from the continent it spreads under the crust of the ocean, and may thus carry on its back marginal portions of the continent and its terrigenous sediments. As the convection current drags these sediments outwards both they and the ocean bottom in front of them will be thrown into simple folds, and where these are sufficiently buoyed up by the stream of sial and their own relative lightness the crests of the folds will rise out of the sea as islands or may form gently folded land masses.

The arcuate form would be due to differing rates of movement of the front of the stream. Where the current moved fastest, the lines of folding would be bowed outward ; while differing speeds of movement at the sides would produce the echelon structures chiefly on the flanks. These folds may not be strictly of ‘ Jura ’ type for the synclines would not necessarily be flat bottomed, as they are in the Jura Mountains, where the movement has taken place on a slide plane.

The sinking of any heavy material in the neighbouring ocean floor would help in the convective movement away from the continent, and the advancing light material would steepen the ocean floor towards the deep.

As an anticline rose out of the sea, its flanks would be depressed, and there would be opportunities for atolls and barrier reefs to form both in front of and behind the islands. The middle front section would move fastest, and in due course would sink towards the deeper parts of the ocean and so produce a submerged ridge. Immediately behind the folded material, which had been brought out from the continent, the crust would be in tension, and any molten material below the solid crust could readily make its way to the surface, thereby producing the lines of volcanoes behind the folds, and pillow lavas would be expected on the sea bottom between the islands and the mainland. There would be many seismic effects during the movements. These movements are roughly indicated in Figure 26.

Island arcs not intimately related to a land-mass may be produced by convection currents below the ocean floor at places where there is sufficient light material to buoy up the rocks to reach the surface of the water. Joly has mentioned [**6**, p. 17] the possibility of convection currents under the oceanic crust due to variations of radioactive content.

This simple explanation of island arcs would appear to be in accord with their structure and peculiarities ; moreover, it links with ideas that sub-crustal movements have produced folded mountain ranges and have also been responsible for the breaking up of continental masses.

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EXPLANATION OF FIG. 26.

A. The hot material is about to move towards the ocean and is creeping under the earth's crust from below the continent to stream out under the oceanic crust.

B. The hot material which includes some sial moving out from the continent and carrying terrigenous sediments into the ocean. These sediments are buoyed up by the light hot material and folded against the crust under the ocean.

C. A later stage where the front fold is sinking towards a deep, and there is a large break in the sediments behind the folding in which volcanic activities occur.

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